secs1d

Carlo de Falco Riccardo Sacco

March 26, 2012

Contents

Table 1: secs1d Package Description

Name:	secs1d
Description:	A Drift-Diffusion simulator for 1d semiconductor devices
Version:	0.0.9
Release Date:	2012-03-25
Author:	Carlo de Falco
Maintainer:	Carlo de Falco
License:	GPL version 2 or later
Depends on:	octave (>= 3.0.0), bim (>= 0.0.0),
Autoload:	No

Part I
Mathematical models

1 Full model

1.1 Conservation laws

$$\begin{cases} -\lambda^2 \text{div } (\varepsilon_r \text{grad } \varphi) = p - n + N_D - N_A \\ -\text{div } (J_n) + R_n\, n = G_n \\ \text{div } (J_p) + R_p\, p = G_p \end{cases} \tag{1}$$

2 Constitutive relations

2.1 Currents

$$\begin{cases} J_n = \quad \mu_n \,(\text{grad } n - n \text{ grad } \varphi) \\ J_p = -\mu_p \,(\text{grad } p + p \text{ grad } \varphi) \end{cases} \tag{2}$$

2.2 Mobilities

$$\begin{cases} \mu_n = \dfrac{2\bar{\mu}_n}{1 + \sqrt{1 + 4\left(\dfrac{\bar{\mu}_n |E|}{v_{sat,n}}\right)^2}}; \qquad \bar{\mu}_n = \mu_{min,n} + \dfrac{\mu_{0,n} - \mu_{min,n}}{1 + \left(\dfrac{N_D + N_A}{N_{ref,n}}\right)^{\beta_n}} \\ \mu_p = \dfrac{2\bar{\mu}_p}{1 + \sqrt{1 + 4\left(\dfrac{\bar{\mu}_p |E|}{v_{sat,p}}\right)^2}}; \qquad \bar{\mu}_p = \mu_{min,p} + \dfrac{\mu_{0,p} - \mu_{min,p}}{1 + \left(\dfrac{N_D + N_A}{N_{ref,p}}\right)^{\beta_p}} \end{cases} \tag{3}$$

2.3 Production terms

$$\begin{cases} R_n = \dfrac{p}{\tau_n(p+\theta)+\tau_p(n+\theta)} + p\left(C_n n + C_p p\right) \\ R_p = \dfrac{n}{\tau_n(p+\theta)+\tau_p(n+\theta)} + n\left(C_n n + C_p p\right) \end{cases} \tag{4}$$

$$G_n = G_p = \frac{\theta^2}{\tau_n(p+\theta)+\tau_p(n+\theta)} + \theta^2\left(C_n n + C_p p\right) + \left(\alpha_n |J_n| + \alpha_p |J_p|\right) \tag{5}$$

$$\begin{cases} \alpha_n = \alpha_n^{\infty} \exp\left(-\dfrac{E_{crit,n}}{|E|}\right) \\ \alpha_p = \alpha_p^{\infty} \exp\left(-\dfrac{E_{crit,p}}{|E|}\right) \end{cases} \tag{6}$$

3 Simplified model used for Newton's method

3.1 Conservation laws

$$\begin{cases} -\lambda^2 \text{div } (\varepsilon_r \text{grad } \varphi) = p - n + N_D - N_A \\ -\text{div } (J_n) + R_n\, n = G_n \\ \text{div } (J_p) + R_p\, p = G_p \end{cases} \tag{7}$$

4 Constitutive relations

4.1 Currents

$$\begin{cases} J_n = \quad \mu_n \,(\text{grad } n - n \text{ grad } \varphi) \\ J_p = -\mu_p \,(\text{grad } p + p \text{ grad } \varphi) \end{cases} \tag{8}$$

4.2 Production terms

$$\begin{cases} R_n = \dfrac{p}{\tau_n(p+\theta) + \tau_p(n+\theta)} + p\,(C_n n + C_p p) \\ R_p = \dfrac{n}{\tau_n(p+\theta) + \tau_p(n+\theta)} + n\,(C_n n + C_p p) \end{cases} \tag{9}$$

$$G_n = G_p = \frac{\theta^2}{\tau_n(p+\theta) + \tau_p(n+\theta)} + \theta^2\,(C_n n + C_p p) \tag{10}$$

5 Scaling factors/adimensional parameters

Given any generic quantity u having units U, we define the *scaled* quantity $\widehat{u}$ as

$$\widehat{u} := \frac{u}{\overline{u}}$$

where $\overline{u}$ is the scaling factor associated with u and having the same units as u.

Scaling factor	Value	Units
$\overline{x}$	L	m
$\overline{n}$	$\|N_D^+ - N_A^-\|_{L^\infty(0,L)}$	m^{-3}
$\overline{\varphi}$	$K_B T/q \simeq 26 \cdot 10^{-3}$	V
$\overline{\mu}$	$\max\{\mu_{0,n},\, \mu_{0,p}\}$	$\mathrm{m}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$
$\overline{t}$	$\overline{x}^2/(\overline{\mu}\,\overline{\varphi})$	s
$\overline{R}$	$\overline{n}/\overline{t}$	$\mathrm{m}^{-3}\mathrm{s}^{-1}$
$\overline{E}$	$\overline{\varphi}/\overline{x}$	$\mathrm{V}\mathrm{m}^{-1}$
$\overline{J}$	$q\,\overline{\mu}\,\overline{n}\,\overline{E}$	$\mathrm{A}\mathrm{m}^{-2}$
$\overline{\alpha}$	$\overline{x}^{-1}$	m^{-1}
$\overline{C}_{Au}$	$\overline{R}/\overline{n}^3$	$\mathrm{m}^6\mathrm{s}^{-1}$

Table 2: Scaling factors for the Drift-Diffusion model equations.

We also introduce the following adimensional numbers

$$\lambda^2 := \frac{\varepsilon_0 \overline{\varphi}}{q\,\overline{n}\,\overline{x}^2}, \qquad \theta := \frac{n_i}{\overline{n}}$$

having the meaning of squared normalized Debye length and normalized intrinsic concentration, respectively.

Part II
Function reference

6 Drift-Diffusion solvers

6.1 secs1d_dd_gummel_map

```
[n, p, V, Fn, Fp, Jn, Jp, it, res] = secs1d_dd_gummel_map (x, D, Na, Nd,
                                                           pin, nin, Vin, Fnin,
                                                           Fpin, l2, er, u0n,
                                                           uminn, vsatn, betan,
                                                           Nrefn, u0p, uminp, vsatp,
                                                           betap, Nrefp, theta, tn, tp,
```

```
                                                    Cn, Cp, an, ap, Ecritnin, Ecritpin,
                                                    toll, maxit, ptoll, pmaxit)

This function solves the scaled stationary bipolar DD
equation system using Gummel algorithm

    input:
           x                        spatial grid
           D, Na, Nd                doping profile
           pin                      initial guess for hole concentration
           nin                      initial guess for electron concentration
           Vin                      initial guess for electrostatic potential
           Fnin                     initial guess for electron Fermi potential
           Fpin                     initial guess for hole Fermi potential
           l2                       scaled Debye length squared
           er                       relative electric permittivity
           u0n, uminn, vsatn, Nrefn electron mobility model coefficients
           u0p, uminp, vsatp, Nrefp hole mobility model coefficients
           theta                    intrinsic carrier density
           tn, tp, Cn, Cp,
           an, ap,
           Ecritnin, Ecritpin       generation recombination model parameters
           toll                     tolerance for Gummel iterarion convergence test
           maxit                    maximum number of Gummel iterarions
           ptoll                    convergence test tolerance for the non linear
                                    Poisson solver
           pmaxit                   maximum number of Newton iterarions

    output:
            n     electron concentration
            p     hole concentration
            V     electrostatic potential
            Fn    electron Fermi potential
            Fp    hole Fermi potential
            Jn    electron current density
            Jp    hole current density
            it    number of Gummel iterations performed
            res   total potential increment at each step
```

6.2 Demo 1 for unction secs1d_dd_gummel_map

```
% physical constants and parameters
secs1d_physical_constants;
secs1d_silicon_material_properties;

% geometry
```

```
L  = 10e-6;          % [m]
xm = L/2;

Nelements = 1000;
x         = linspace (0, L, Nelements+1)';
sinodes   = [1:length(x)];

% dielectric constant (silicon)
er = esir * ones (Nelements, 1);

% doping profile [m^{-3}]
Na = 1e23 * (x <= xm);
Nd = 1e23 * (x > xm);

% avoid zero doping
D  = Nd - Na;

% initial guess for n, p, V, phin, phip
V_p = -1;
V_n =  0;

Fp = V_p * (x <= xm);
Fn = Fp;

p = abs (D) / 2 .* (1 + sqrt (1 + 4 * (ni./abs(D)) .^2)) .* (x <= xm) + ...
    ni^2 ./ (abs (D) / 2 .* (1 + sqrt (1 + 4 * (ni ./ abs (D)) .^2))) .* (x > xm);

n = abs (D) / 2 .* (1 + sqrt (1 + 4 * (ni ./ abs (D)) .^ 2)) .* (x > xm) + ...
    ni ^ 2 ./ (abs (D) / 2 .* (1 + sqrt (1 + 4 * (ni ./ abs (D)) .^2))) .* (x <= xm);

V = Fn + Vth * log (n / ni);

% scaling factors
xbar = L;                        % [m]
nbar = norm(D, 'inf');           % [m^{-3}]
Vbar = Vth;                      % [V]
mubar = max (u0n, u0p);          % [m^2 V^{-1} s^{-1}]
tbar = xbar^2 / (mubar * Vbar); % [s]
Rbar = nbar / tbar;              % [m^{-3} s^{-1}]
Ebar = Vbar / xbar;              % [V m^{-1}]
Jbar = q * mubar * nbar * Ebar; % [A m^{-2}]
CAubar = Rbar / nbar^3;          % [m^6 s^{-1}]
abar = 1/xbar;                   % [m^{-1}]

% scaling procedure
l2 = e0 * Vbar / (q * nbar * xbar^2);
theta = ni / nbar;

xin = x / xbar;
```

```
Din = D / nbar;
Nain = Na / nbar;
Ndin = Nd / nbar;
pin = p / nbar;
nin = n / nbar;
Vin = V / Vbar;
Fnin = Vin - log (nin);
Fpin = Vin + log (pin);

tnin = tn / tbar;
tpin = tp / tbar;

u0nin = u0n / mubar;
uminnin = uminn / mubar;
vsatnin = vsatn / (mubar * Ebar);

u0pin = u0p / mubar;
uminpin = uminp / mubar;
vsatpin = vsatp / (mubar * Ebar);

Nrefnin = Nrefn / nbar;
Nrefpin = Nrefp / nbar;

Cnin     = Cn / CAubar;
Cpin     = Cp / CAubar;

anin     = an / abar;
apin     = ap / abar;
Ecritnin = Ecritn / Ebar;
Ecritpin = Ecritp / Ebar;

% tolerances for convergence checks
toll  = 1e-3;
maxit = 1000;
ptoll = 1e-12;
pmaxit = 1000;

% solve the problem using the full DD model
[nout, pout, Vout, Fnout, Fpout, Jnout, Jpout, it, res] = ...
      secs1d_dd_gummel_map (xin, Din, Nain, Ndin, pin, nin, Vin, Fnin, Fpin, ...
                            l2, er, u0nin, uminnin, vsatnin, betan, Nrefnin, ...
                        u0pin, uminpin, vsatpin, betap, Nrefpin, theta, ...
                tnin, tpin, Cnin, Cpin, anin, apin, ...
                Ecritnin, Ecritpin, toll, maxit, ptoll, pmaxit);

% Descaling procedure
n    = nout*nbar;
p    = pout*nbar;
V    = Vout*Vbar;
```

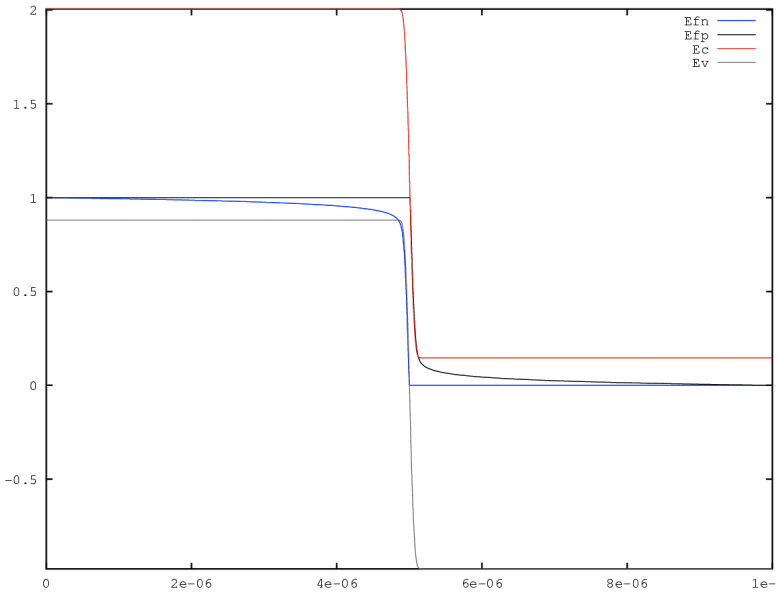

Figure 1: Figure produced by demo number 1 for function secs1d_dd_gummel_map

```
Fn   = V - Vth*log(n/ni);
Fp   = V + Vth*log(p/ni);
dV   = diff(V);
dx   = diff(x);
E    = -dV./dx;

% band structure
Efn  = -Fn;
Efp  = -Fp;
Ec   = Vth*log(Nc./n)+Efn;
Ev   = -Vth*log(Nv./p)+Efp;

plot (x, Efn, x, Efp, x, Ec, x, Ev)
legend ('Efn', 'Efp', 'Ec', 'Ev')
axis tight
```

6.3 secs1d_dd_newton

```
[n, p, V, Fn, Fp, Jn, Jp, it, res] = secs1d_dd_newton (x, D, Vin, nin,
                                                       pin, l2, er, un,
                                                       up, theta, tn, tp,
                                                       Cn, Cp, toll, maxit)

Solve the scaled stationary bipolar DD equation system using Newton's method

    input:
      x                spatial grid
      D                doping profile
      pin              initial guess for hole concentration
      nin              initial guess for electron concentration
      Vin              initial guess for electrostatic potential
      l2               scaled Debye length squared
      er               relative electric permittivity
      un               electron mobility model coefficients
      up               electron mobility model coefficients
      theta            intrinsic carrier density
      tn, tp, Cn, Cp   generation recombination model parameters
      toll             tolerance for Gummel iterarion convergence test
      maxit            maximum number of Gummel iterarions

    output:
      n     electron concentration
      p     hole concentration
      V     electrostatic potential
      Fn    electron Fermi potential
      Fp    hole Fermi potential
      Jn    electron current density
      Jp    hole current density
      it    number of Gummel iterations performed
      res   total potential increment at each step
```

6.4 Demo 1 for function secs1d_dd_newton

```
% physical constants and parameters
secs1d_physical_constants;
secs1d_silicon_material_properties;

% geometry
L  = 1e-6; % [m]
x  = linspace (0, L, 10)';
sinodes = [1:length(x)];
```

```
% dielectric constant (silicon)
er = esir * ones (numel (x) - 1, 1);

% doping profile [m^{-3}]
Na = 1e20 * ones(size(x));
Nd = 1e24 * ones(size(x));
D  = Nd-Na;

% externally applied voltages
V_p = 10;
V_n = 0;

% initial guess for phin, phip, n, p, V
Fp = V_p * (x <= L/2);
Fn = Fp;

p = abs(D)/2.*(1+sqrt(1+4*(ni./abs(D)).^2)).*(D<0)+...
    ni^2./(abs(D)/2.*(1+sqrt(1+4*(ni./abs(D)).^2))).*(D>0);

n = abs(D)/2.*(1+sqrt(1+4*(ni./abs(D)).^2)).*(D>0)+...
    ni^2./(abs(D)/2.*(1+sqrt(1+4*(ni./abs(D)).^2))).*(D<0);

V  = Fn + Vth*log(n/ni);

% scaling factors
xbar = L;                          % [m]
nbar = norm(D, 'inf');             % [m^{-3}]
Vbar = Vth;                        % [V]
mubar = max(u0n, u0p);             % [m^2 V^{-1} s^{-1}]
tbar = xbar^2/(mubar*Vbar);        % [s]
Rbar = nbar/tbar;                  % [m^{-3} s^{-1}]
Ebar = Vbar/xbar;                  % [V m^{-1}]
Jbar = q*mubar*nbar*Ebar;          % [A m^{-2}]
CAubar = Rbar/nbar^3;              % [m^6 s^{-1}]
abar = xbar^(-1);                  % [m^{-1}]

% scaling procedure
l2 = e0*Vbar/(q*nbar*xbar^2);
theta = ni/nbar;

xin = x/xbar;
Din = D/nbar;
Nain = Na/nbar;
Ndin = Nd/nbar;
pin = p/nbar;
nin = n/nbar;
Vin = V/Vbar;
Fnin = Vin - log(nin);
```

```
Fpin = Vin + log(pin);

tnin = tn/tbar;
tpin = tp/tbar;

% mobility model accounting scattering from ionized impurities
u0nin = u0n/mubar;
uminnin = uminn/mubar;
vsatnin = vsatn/(mubar*Ebar);

u0pin = u0p/mubar;
uminpin = uminp/mubar;
vsatpin = vsatp/(mubar*Ebar);

Nrefnin = Nrefn/nbar;
Nrefpin = Nrefp/nbar;

Cnin     = Cn/CAubar;
Cpin     = Cp/CAubar;

anin     = an/abar;
apin     = ap/abar;
Ecritnin = Ecritn/Ebar;
Ecritpin = Ecritp/Ebar;

% tolerances for convergence checks
ptoll = 1e-12;
pmaxit = 1000;

% solve the problem using the Newton fully coupled iterative algorithm
[nout, pout, Vout, Fnout, Fpout, Jnout, Jpout, it, res] = secs1d_dd_newton (xin, Din,
                                                                  Vin, nin, pin, l2, er,
                                                                  u0nin, u0pin, theta, tnin,
                                                                  tpin, Cnin, Cpin, ptoll, pmaxit);
% Descaling procedure
n    = nout*nbar;
p    = pout*nbar;
V    = Vout*Vbar;
Fn   = V - Vth*log(n/ni);
Fp   = V + Vth*log(p/ni);
dV   = diff(V);
dx   = diff(x);
E    = -dV./dx;

% compute current densities
[Bp, Bm] = bimu_bernoulli (dV/Vth);
Jn       =  q*u0n*Vth .* (n(2:end) .* Bp - n(1:end-1) .* Bm) ./ dx;
Jp       = -q*u0p*Vth .* (p(2:end) .* Bm - p(1:end-1) .* Bp) ./ dx;
Jtot     =  Jn+Jp;
```

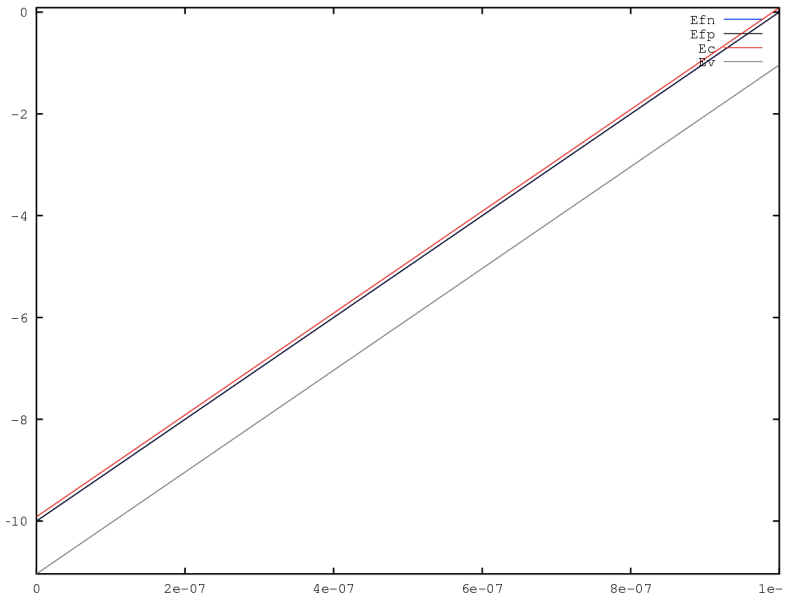

Figure 2: Figure produced by demo number 1 for function secs1d_dd_newton

```
% band structure
Efn  = -Fn;
Efp  = -Fp;
Ec   = Vth*log(Nc./n)+Efn;
Ev   = -Vth*log(Nv./p)+Efp;

plot (x, Efn, x, Efp, x, Ec, x, Ev)
legend ('Efn', 'Efp', 'Ec', 'Ev')
axis tight
```

7 Non-linear Poisson solver

7.1 secs1d_nlpoisson_newton

```
[V, n, p, res, niter] = secs1d_nlpoisson_newton (x, sinodes, Vin, nin, pin,
                                                 Fnin, Fpin, D, l2, er, toll, maxit)

    input:
            x       spatial grid
            sinodes index of the nodes of the grid which are in the semiconductor subdomain
                    (remaining nodes are assumed to be in the oxide subdomain)
            Vin     initial guess for the electrostatic potential
            nin     initial guess for electron concentration
            pin     initial guess for hole concentration
            Fnin    initial guess for electron Fermi potential
            Fpin    initial guess for hole Fermi potential
            D       doping profile
            l2      scaled Debye length squared
            er      relative electric permittivity
            toll    tolerance for convergence test
            maxit   maximum number of Newton iterations

    output:
            V       electrostatic potential
            n       electron concentration
            p       hole concentration
            res     residual norm at each step
            niter   number of Newton iterations
```

7.2 Demo 1 for function secs1d_nlpoisson_newton

```
secs1d_physical_constants
secs1d_silicon_material_properties

tbulk= 1.5e-6;
tox = 90e-9;
L = tbulk + tox;
cox = esio2/tox;

Nx  = 50;
Nel = Nx - 1;

x = linspace (0, L, Nx)';
sinodes = find (x <= tbulk);
xsi = x(sinodes);
```

```
Nsi = length (sinodes);
Nox = Nx - Nsi;

NelSi   = Nsi - 1;
NelSiO2 = Nox - 1;

Na = 1e22;
D = - Na * ones (size (xsi));
p = Na * ones (size (xsi));
n = (ni^2) ./ p;
Fn = Fp = zeros (size (xsi));
Vg = -10;
Nv = 80;
for ii = 1:Nv
    Vg = Vg + 0.2;
    vvect(ii) = Vg;

    V = - Phims + Vg * ones (size (x));
    V(sinodes) = Fn + Vth * log (n/ni);

    % Scaling
    xs  = L;
    ns  = norm (D, inf);
    Din = D / ns;
    Vs  = Vth;
    xin   = x / xs;
    nin   = n / ns;
    pin   = p / ns;
    Vin   = V / Vs;
    Fnin  = (Fn - Vs * log (ni / ns)) / Vs;
    Fpin  = (Fp + Vs * log (ni / ns)) / Vs;

    er    = esio2r * ones(Nel, 1);
    l2(1:NelSi) = esi;
    l2    = (Vs*e0)/(q*ns*xs^2);

    % Solution of Nonlinear Poisson equation

    % Algorithm parameters
    toll  = 1e-10;
    maxit = 1000;

    [V, nout, pout, res, niter] = secs1d_nlpoisson_newton (xin, sinodes,
                                                           Vin, nin, pin,
                                                           Fnin, Fpin, Din, l2,
                                                           er, toll, maxit);

    % Descaling
```

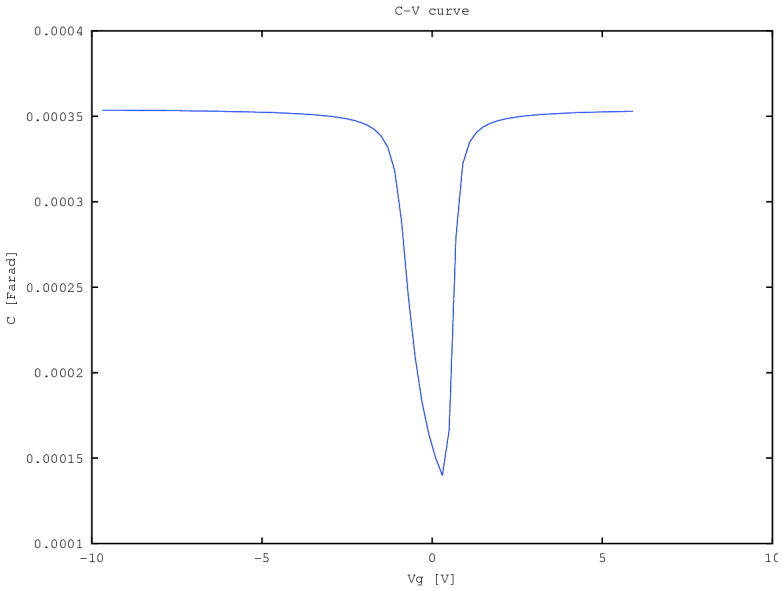

Figure 3: Figure produced by demo number 1 for function secs1d_nlpoisson_newton

```
    n      = nout*ns;
    p      = pout*ns;
    V      = V*Vs;

    qtot(ii) = q * trapz (xsi, p + D - n);
end

vvectm = (vvect(2:end)+vvect(1:end-1))/2;
C = - diff (qtot) ./ diff (vvect);
plot(vvectm, C)
xlabel('Vg [V]')
ylabel('C [Farad]')
title('C-V curve')
```

8 Physical constants and material properties

8.1 secs1d_physical_constants.m

```
some useful physical constants

Kb       = Boltzman constant
q        = quantum of charge
e0       = permittivity of free space
hplanck  = Plank constant
hbar     = Plank constant by 2 pi
mn0      = free electron mass
T0       = temperature
Vth     = thermal voltage
```

8.2 secs1d_silicon_material_properties.m

```
material properties for silicon and silicon dioxide

esir       = relative electric permittivity of silicon
esio2r     = relative electric permittivity of silicon dioxide
esi        = electric permittivity of silicon
esio2      = electric permittivity of silicon dioxide
mn         = effective mass of electrons in silicon
mh         = effective mass of holes in silicon

u0n        = low field electron mobility
u0p        = low field hole mobility
uminn      = parameter for doping-dependent electron mobility
betan      = idem
Nrefn      = idem
uminp      = parameter for doping-dependent hole mobility
betap      = idem
Nrefp      = idem
vsatn      = electron saturation velocity
vsatp      = hole saturation velocity
tp         = electron lifetime
tn         = hole lifetime
Cn         = electron Auger coefficient
Cp         = hole Auger coefficient
an         = impact ionization rate for electrons
ap         = impact ionization rate for holes
Ecritn     = critical field for impact ionization of electrons
Ecritp     = critical field for impact ionization of holes
Nc         = effective density of states in the conduction band
Nv         = effective density of states in the valence band
Egap       = bandgap in silicon
EgapSio2   = bandgap in silicon dioxide

ni         = intrinsic carrier density
Phims      = metal to semiconductor potential barrier
```

A Licence

GNU GENERAL PUBLIC LICENSE
Version 2, June 1991

Preamble

The licenses for most software are designed to take away your freedom to share and change it. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change free software--to make sure the software is free for all its users. This General Public License applies to most of the Free Software Foundation's software and to any other program whose authors commit to using it. (Some other Free Software Foundation software is covered by the GNU Library General Public License instead.) You can apply it to your programs, too.

When we speak of free software, we are referring to freedom, not price. Our General Public Licenses are designed to make sure that you have the freedom to distribute copies of free software (and charge for this service if you wish), that you receive source code or can get it if you want it, that you can change the software or use pieces of it in new free programs; and that you know you can do these things.

To protect your rights, we need to make restrictions that forbid anyone to deny you these rights or to ask you to surrender the rights. These restrictions translate to certain responsibilities for you if you distribute copies of the software, or if you modify it.

For example, if you distribute copies of such a program, whether gratis or for a fee, you must give the recipients all the rights that you have. You must make sure that they, too, receive or can get the source code. And you must show them these terms so they know their rights.

We protect your rights with two steps: (1) copyright the software, and (2) offer you this license which gives you legal permission to copy, distribute and/or modify the software.

Also, for each author's protection and ours, we want to make certain that everyone understands that there is no warranty for this free software. If the software is modified by someone else and passed on, we want its recipients to know that what they have is not the original, so that any problems introduced by others will not reflect on the original authors' reputations.

Finally, any free program is threatened constantly by software patents. We wish to avoid the danger that redistributors of a free program will individually obtain patent licenses, in effect making the program proprietary. To prevent this, we have made it clear that any patent must be licensed for everyone's free use or not licensed at all.

The precise terms and conditions for copying, distribution and modification follow.
↓

GNU GENERAL PUBLIC LICENSE
TERMS AND CONDITIONS FOR COPYING, DISTRIBUTION AND MODIFICATION

0. This License applies to any program or other work which contains a notice placed by the copyright holder saying it may be distributed under the terms of this General Public License. The "Program", below, refers to any such program or work, and a "work based on the Program" means either the Program or any derivative work under copyright law: that is to say, a work containing the Program or a portion of it, either verbatim or with modifications and/or translated into another language. (Hereinafter, translation is included without limitation in the term "modification".) Each licensee is addressed as "you".

Activities other than copying, distribution and modification are not covered by this License; they are outside its scope. The act of running the Program is not restricted, and the output from the Program is covered only if its contents constitute a work based on the Program (independent of having been made by running the Program). Whether that is true depends on what the Program does.

1. You may copy and distribute verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice and disclaimer of warranty; keep intact all the notices that refer to this License and to the absence of any warranty; and give any other recipients of the Program a copy of this License along with the Program.

You may charge a fee for the physical act of transferring a copy, and you may at your option offer warranty protection in exchange for a fee.

2. You may modify your copy or copies of the Program or any portion of it, thus forming a work based on the Program, and copy and distribute such modifications or work under the terms of Section 1 above, provided that you also meet all of these conditions:

a) You must cause the modified files to carry prominent notices stating that you changed the files and the date of any change.

b) You must cause any work that you distribute or publish, that in whole or in part contains or is derived from the Program or any part thereof, to be licensed as a whole at no charge to all third parties under the terms of this License.

c) If the modified program normally reads commands interactively when run, you must cause it, when started running for such interactive use in the most ordinary way, to print or display an announcement including an appropriate copyright notice and a notice that there is no warranty (or else, saying that you provide a warranty) and that users may redistribute the program under these conditions, and telling the user how to view a copy of this License. (Exception: if the Program itself is interactive but does not normally print such an announcement, your work based on the Program is not required to print an announcement.)

↓

These requirements apply to the modified work as a whole. If identifiable sections of that work are not derived from the Program, and can be reasonably considered independent and separate works in themselves, then this License, and its terms, do not apply to those sections when you distribute them as separate works. But when you distribute the same sections as part of a whole which is a work based on the Program, the distribution of the whole must be on the terms of this License, whose permissions for other licensees extend to the entire whole, and thus to each and every part regardless of who wrote it.

Thus, it is not the intent of this section to claim rights or contest your rights to work written entirely by you; rather, the intent is to exercise the right to control the distribution of derivative or collective works based on the Program.

In addition, mere aggregation of another work not based on the Program with the Program (or with a work based on the Program) on a volume of a storage or distribution medium does not bring the other work under the scope of this License.

3. You may copy and distribute the Program (or a work based on it, under Section 2) in object code or executable form under the terms of Sections 1 and 2 above provided that you also do one of the following:

a) Accompany it with the complete corresponding machine-readable source code, which must be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,

b) Accompany it with a written offer, valid for at least three years, to give any third party, for a charge no more than your cost of physically performing source distribution, a complete machine-readable copy of the corresponding source code, to be distributed under the terms of Sections 1 and 2 above on a medium

customarily used for software interchange; or,

c) Accompany it with the information you received as to the offer to distribute corresponding source code. (This alternative is allowed only for noncommercial distribution and only if you received the program in object code or executable form with such an offer, in accord with Subsection b above.)

The source code for a work means the preferred form of the work for making modifications to it. For an executable work, complete source code means all the source code for all modules it contains, plus any associated interface definition files, plus the scripts used to control compilation and installation of the executable. However, as a special exception, the source code distributed need not include anything that is normally distributed (in either source or binary form) with the major components (compiler, kernel, and so on) of the operating system on which the executable runs, unless that component itself accompanies the executable.

If distribution of executable or object code is made by offering access to copy from a designated place, then offering equivalent access to copy the source code from the same place counts as distribution of the source code, even though third parties are not compelled to copy the source along with the object code.
↓

4. You may not copy, modify, sublicense, or distribute the Program except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense or distribute the Program is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

5. You are not required to accept this License, since you have not signed it. However, nothing else grants you permission to modify or distribute the Program or its derivative works. These actions are prohibited by law if you do not accept this License. Therefore, by modifying or distributing the Program (or any work based on the Program), you indicate your acceptance of this License to do so, and all its terms and conditions for copying, distributing or modifying the Program or works based on it.

6. Each time you redistribute the Program (or any work based on the Program), the recipient automatically receives a license from the original licensor to copy, distribute or modify the Program subject to these terms and conditions. You may not impose any further restrictions on the recipients' exercise of the rights granted herein. You are not responsible for enforcing compliance by third parties to this License.

7. If, as a consequence of a court judgment or allegation of patent infringement or for any other reason (not limited to patent issues), conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot distribute so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not distribute the Program at all. For example, if a patent license would not permit royalty-free redistribution of the Program by all those who receive copies directly or indirectly through you, then the only way you could satisfy both it and this License would be to refrain entirely from distribution of the Program.

If any portion of this section is held invalid or unenforceable under any particular circumstance, the balance of the section is intended to apply and the section as a whole is intended to apply in other circumstances.

It is not the purpose of this section to induce you to infringe any patents or other property right claims or to contest validity of any such claims; this section has the sole purpose of protecting the integrity of the free software distribution system, which is implemented by public license practices. Many people have made generous contributions to the wide range of software distributed through that system in reliance on consistent application of that system; it is up to the author/donor to decide if he or she is willing to distribute software through any other system and a licensee cannot impose that choice.

This section is intended to make thoroughly clear what is believed to be a consequence of the rest of this License.
↓
8. If the distribution and/or use of the Program is restricted in certain countries either by patents or by copyrighted interfaces, the original copyright holder who places the Program under this License may add an explicit geographical distribution limitation excluding those countries, so that distribution is permitted only in or among countries not thus excluded. In such case, this License incorporates the limitation as if written in the body of this License.

9. The Free Software Foundation may publish revised and/or new versions of the General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies a version number of this License which applies to it and "any later version", you have the option of following the terms and conditions

either of that version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of this License, you may choose any version ever published by the Free Software Foundation.

10. If you wish to incorporate parts of the Program into other free programs whose distribution conditions are different, write to the author to ask for permission. For software which is copyrighted by the Free Software Foundation, write to the Free Software Foundation; we sometimes make exceptions for this. Our decision will be guided by the two goals of preserving the free status of all derivatives of our free software and of promoting the sharing and reuse of software generally.

NO WARRANTY

11. BECAUSE THE PROGRAM IS LICENSED FREE OF CHARGE, THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.

12. IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MAY MODIFY AND/OR REDISTRIBUTE THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

END OF TERMS AND CONDITIONS

↓

How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to the public, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively convey the exclusion of warranty; and each file should have at least the "copyright" line and a pointer to where the full notice is found.

<one line to give the program’s name and a brief idea of what it does.>

```
    Copyright (C) <year>  <name of author>

    This program is free software; you can redistribute it and/or modify
    it under the terms of the GNU General Public License as published by
    the Free Software Foundation; either version 2 of the License, or
    (at your option) any later version.

    This program is distributed in the hope that it will be useful,
    but WITHOUT ANY WARRANTY; without even the implied warranty of
    MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
    GNU General Public License for more details.

    You should have received a copy of the GNU General Public License
    along with this program; if not, see <http://www.gnu.org/licenses/>.
```

Also add information on how to contact you by electronic and paper mail.

If the program is interactive, make it output a short notice like this when it starts in an interactive mode:

```
    Gnomovision version 69, Copyright (C) year name of author
    Gnomovision comes with ABSOLUTELY NO WARRANTY; for details type ‘show w’.
    This is free software, and you are welcome to redistribute it
    under certain conditions; type ‘show c’ for details.
```

The hypothetical commands ‘show w’ and ‘show c’ should show the appropriate parts of the General Public License. Of course, the commands you use may be called something other than ‘show w’ and ‘show c’; they could even be mouse-clicks or menu items--whatever suits your program.

You should also get your employer (if you work as a programmer) or your school, if any, to sign a "copyright disclaimer" for the program, if necessary. Here is a sample; alter the names:

```
  Yoyodyne, Inc., hereby disclaims all copyright interest in the program
  ‘Gnomovision’ (which makes passes at compilers) written by James Hacker.

  <signature of Ty Coon>, 1 April 1989
  Ty Coon, President of Vice
```

This General Public License does not permit incorporating your program into proprietary programs. If your program is a subroutine library, you may consider it more useful to permit linking proprietary applications with the library. If this is what you want to do, use the GNU Library General Public License instead of this License.