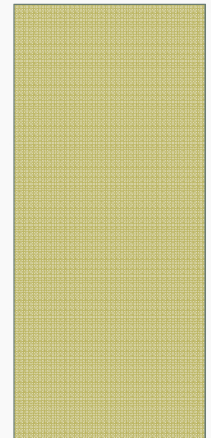
# MODELING OF LEDS WITH SILVACO

DRAGICA VASILESKA



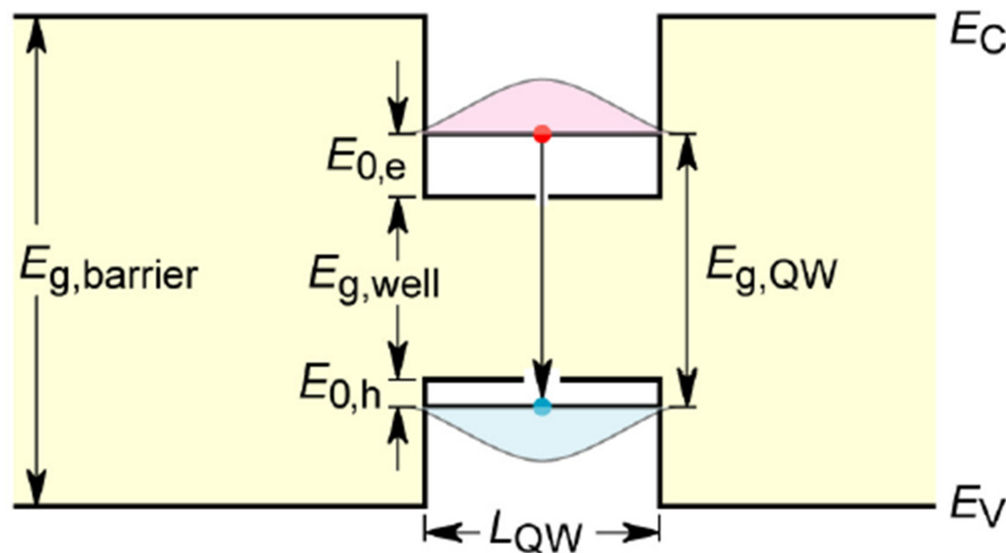
# OUTLINE

- Introductory Concepts
- Example 1: Single Quantum Well Blue GaN LED
- Example 2: Multiple Quantum Well UV LED

# INTRODUCTORY CONCEPTS

# SINGLE AND MULTIPLE QUANTUM WELL STRUCTURES

A QW is synthesized from two different semiconductors. Consider two semiconductors with bandgap $E_{g,\ barrier}$ and $E_{g,\ well}$. If the band alignment is straddled, the following QW band diagram is obtained:



- If $L_{QW}$ is large, quasi-3D behavior is obtained. Size quantization is then negligibly small.
- If $L_{QW}$ is sufficiently small, size quantization occurs.
- Absorption edge of the structure:

$$E_{g,\,QW} = E_{g,\,well} + E_{0,\,e} + E_{0,\,h}$$

... where $E_{0,\,e}$ is quantized electron energy
... where $E_{0,\,h}$ is quantized hole energy

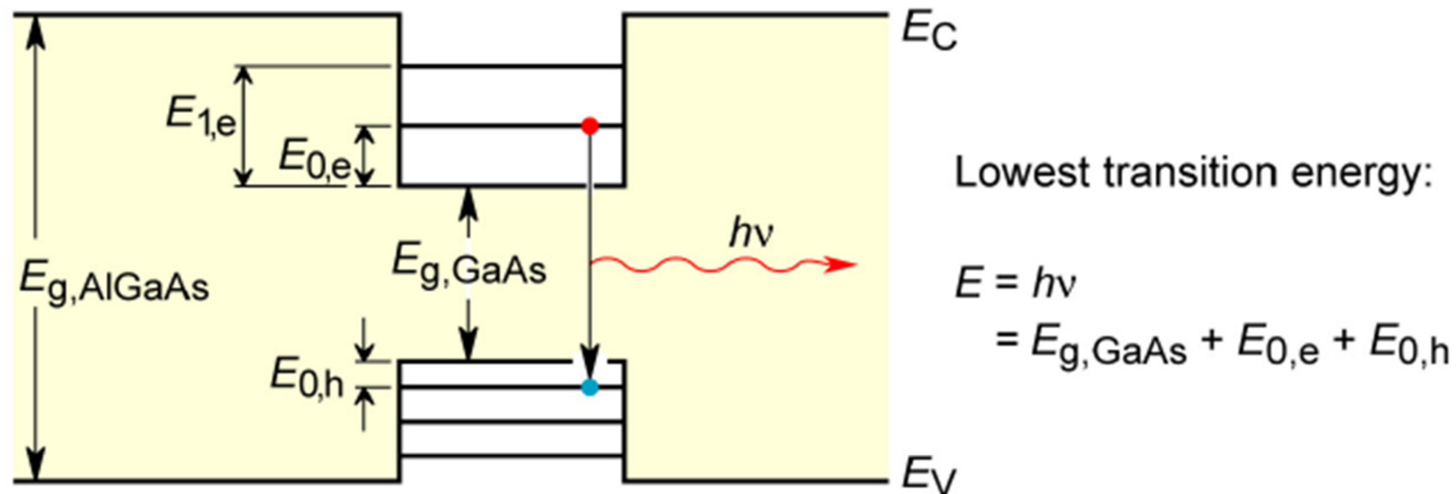
- Emission energy = $E_{g,\,QW} = h\nu$
- The emission energy of the QW is different from either bandgap energy of the two semiconductors. Thus, a new synthetic material has been formed that is only remotely related to the bulk materials it is made of. This is why QWs are exciting materials.

### *Advantages of QW structures*

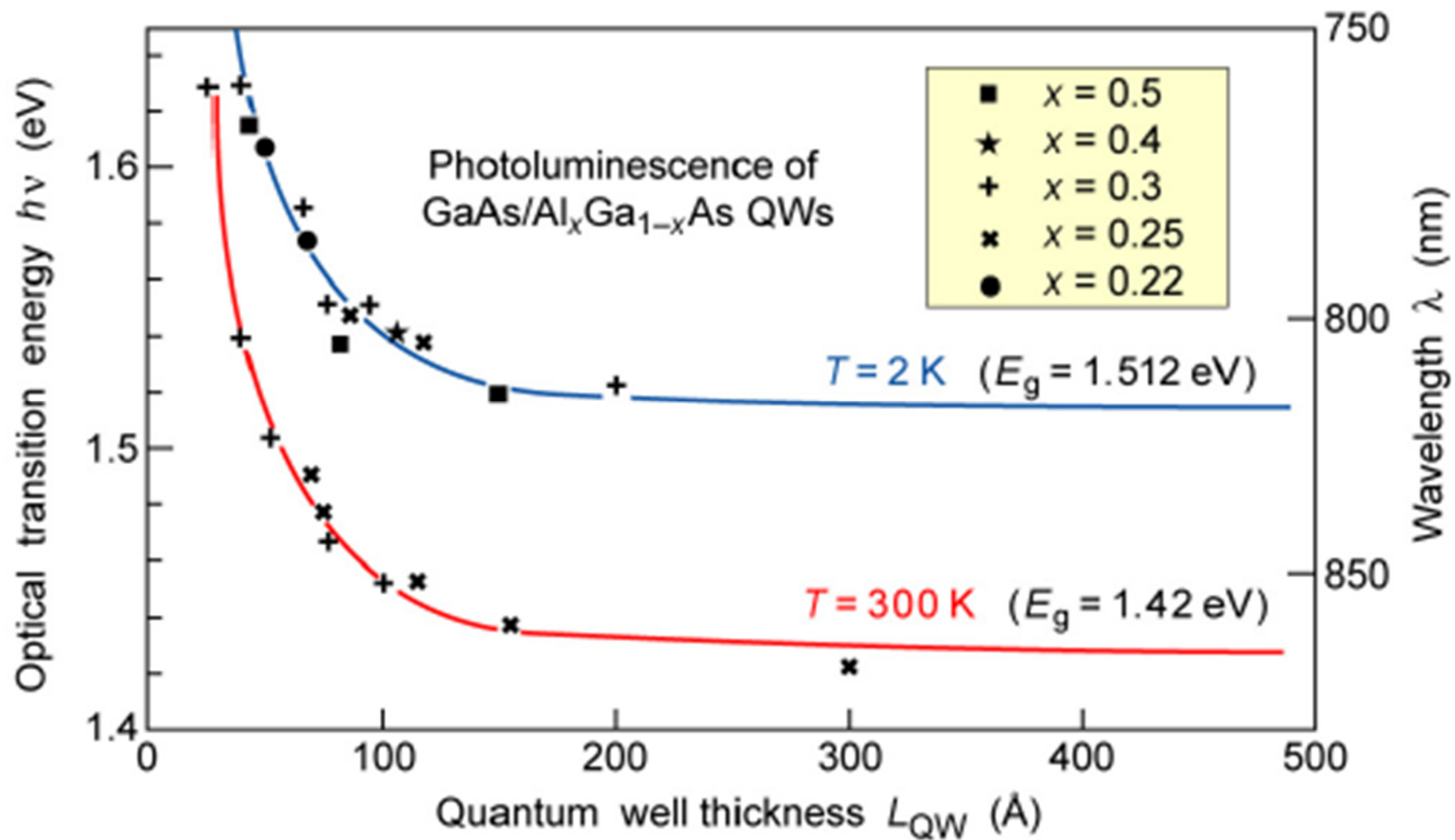
Why are QW structures advantageous?

- Freedom to design transition energies
- High radiative efficiency. QW structures have a small volume. Therefore, when carriers are injected into a QW structure, the free carrier concentration in a QW is high. At high free carrier concentrations, non-radiative deep-level transitions are less likely. (Why?) QW structures therefore have high radiative efficiency.
- Low laser thresholds. Due to the small volume, the carrier density required to achieve population inversion is small. Therefore the threshold current density of QW structures is low.
- Surface recombination. Surface recombination is less important in QW structures as compared to bulk material. In QW structures, carriers are trapped by the QW and, therefore, cannot reach the surface. This is shown in the following figure:

## *GaAs QWs*

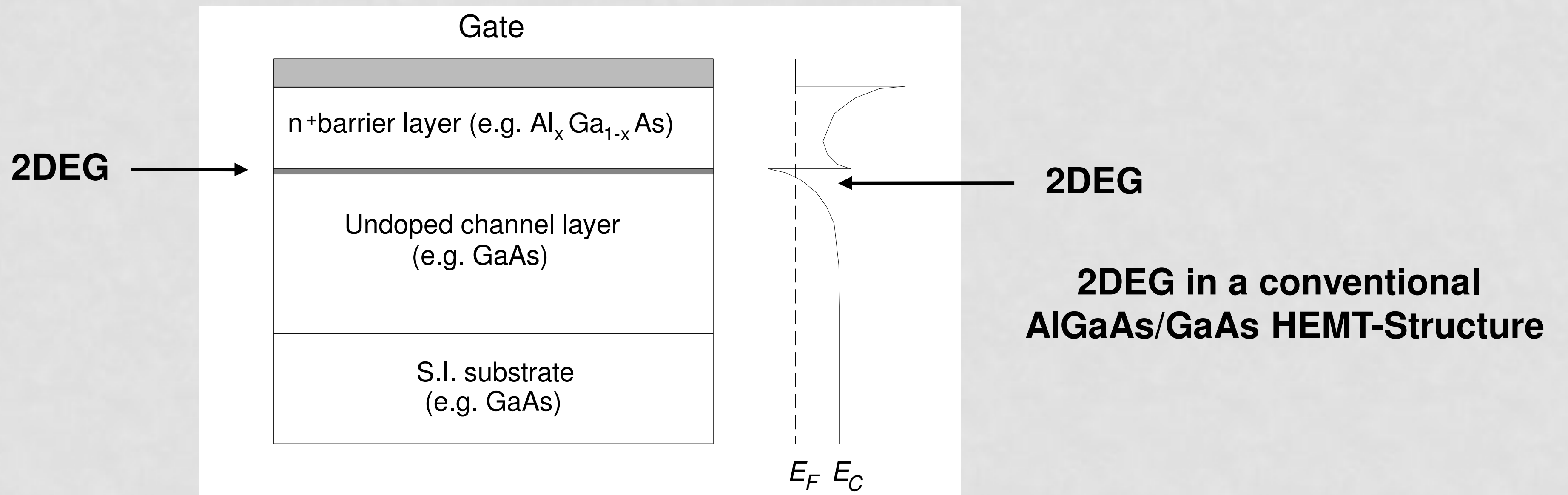



- AlGaAs / GaAs is a frequently used QW system
- AlGaAs / GaAs is lattice matched for all Al compositions to the GaAs substrates
- Luminescence emission measurements allow one to determine the energy shift due to the quantum size effect. The following graph shows experimental QW emission energies versus QW thickness:

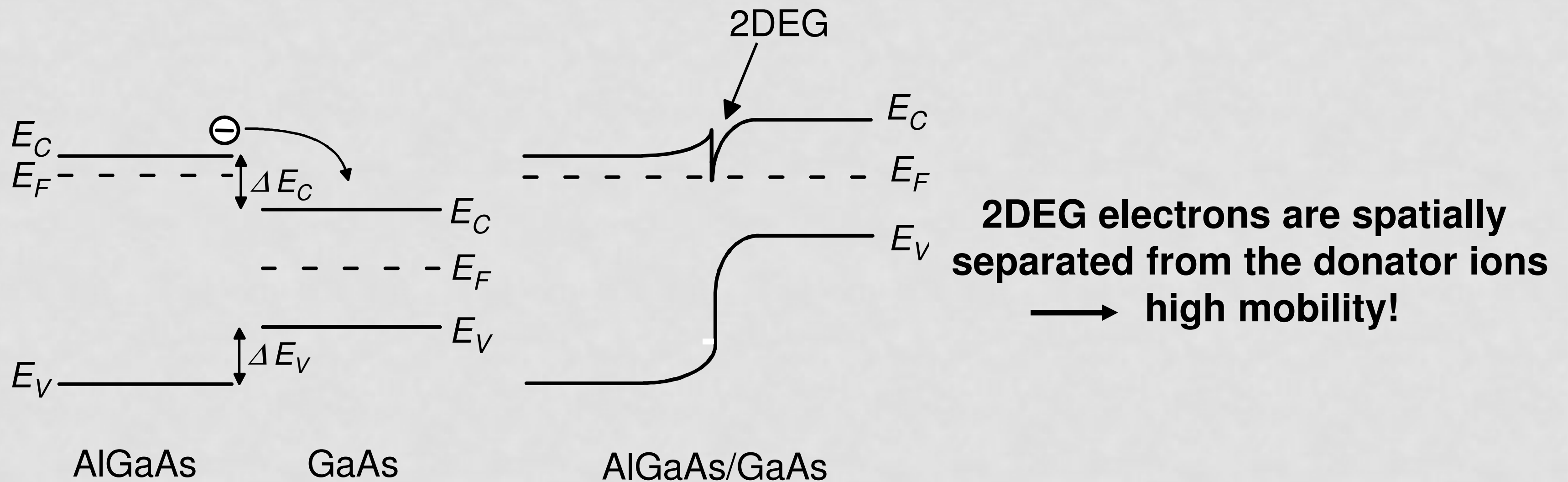


Photoluminescence of
GaAs/Al$_x$Ga$_{1-x}$As QWs
x = 0.5
x = 0.4
x = 0.3
x = 0.25
x = 0.22
T = 2 K (E$_g$ = 1.512 eV)
T = 300 K (E$_g$ = 1.42 eV)
Optical transition energy hν (eV)
Wavelength λ (nm)
Quantum well thickness L$_{QW}$ (Å)
1.4
1.5
1.6
0
100
200
300
400
500
750
800
850

# Two-Dimensional Electron Gas - 2DEG




**2DEG in a conventional AlGaAs/GaAs HEMT-Structure**




**2DEG electrons are spatially separated from the donator ions**
**⟶ high mobility!**

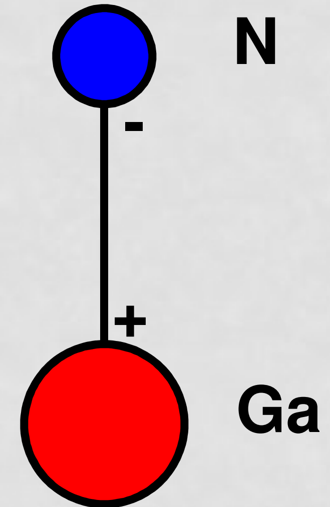
# *PROPERTIES OF 2DEGS*

| Heterojunction Type | $\mu_0$, $cm^2/Vs$ | $n_S$, $cm^{-2}$ | $\Delta E_G$, eV | $\Delta E_C$, eV |
|---|---|---|---|---|
| $Al_{0.3}Ga_{0.7}As/GaAs$ | 5400 | **$1.4 \times 10^{12}$** | 0.38 | 0.22 |
| $Al_{0.3}Ga_{0.7}As/In_{0.2}Ga_{0.8}As$ | 6400 | **$2.2 \times 10^{12}$** | 0.58 | 0.41 |
| $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ | 10 000 | **$3.0 \times 10^{12}$** | 0.71 | 0.52 |
| $Al_{0.3}Ga_{0.7}N/GaN$ | 1 400 | **$1.3 \times 10^{13}$** | 0.6 | 0.42 |

**III-V heterostructures: - more In in the channel layer leads to higher mobility $\mu_0$**
**- larger $\Delta E_C$ causes a higher higher sheet concentration $n_S$**

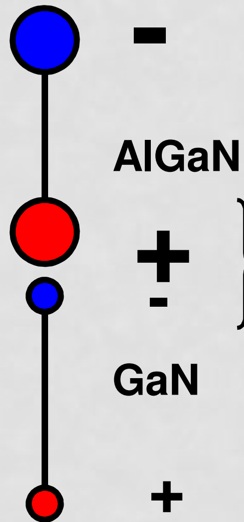
**AlGaN/GaN: - lower mobility than III-V's**
**- rather moderate $\Delta E_C$ but extremely high $n_S$ - WHY ?**

# 2DEGs in AlGaN/GaN Structures




- Electronegativity
  polar nature of the bonds in AlGaN and GaN
- Deviation of the GaN and AlGaN crystal
  structure from the ideal structure:
  spontaneous polarization
- Different spontaneous polarizations in AlGaN and GaN
  gradient of the polarization at the interface
- Difference in the lattice constants in AlGaN and GaN
  strained AlGaN additional polarisation component:
  piezoelectric polarization

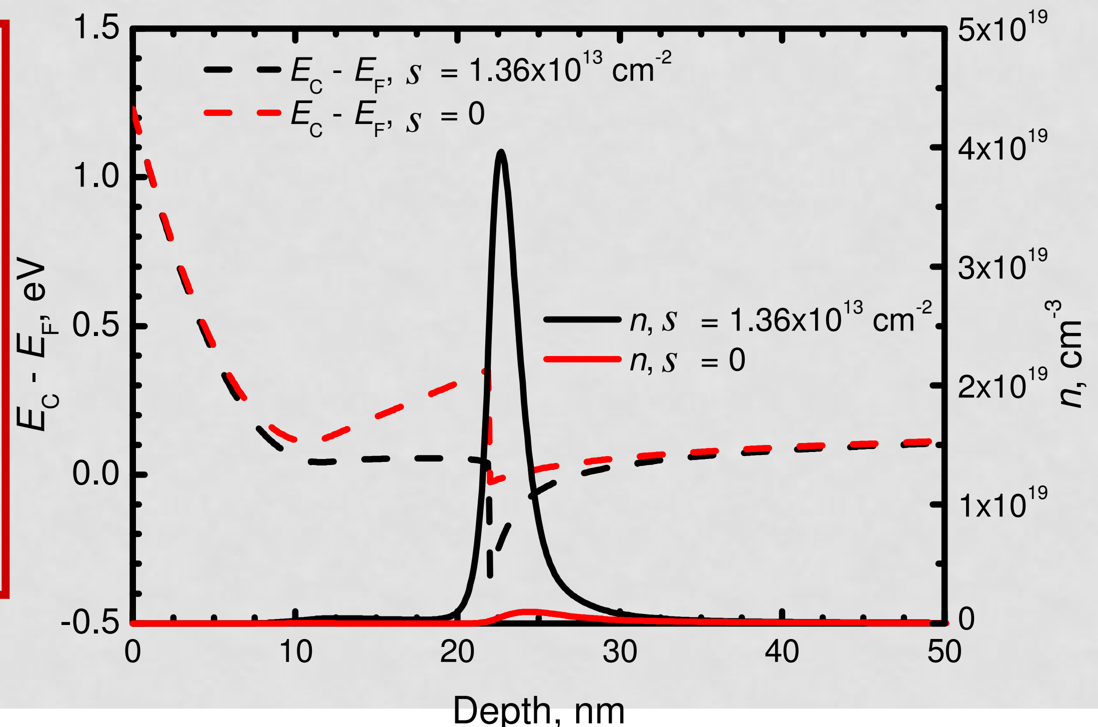
# 2DEGs in AlGaN/GaN Structures



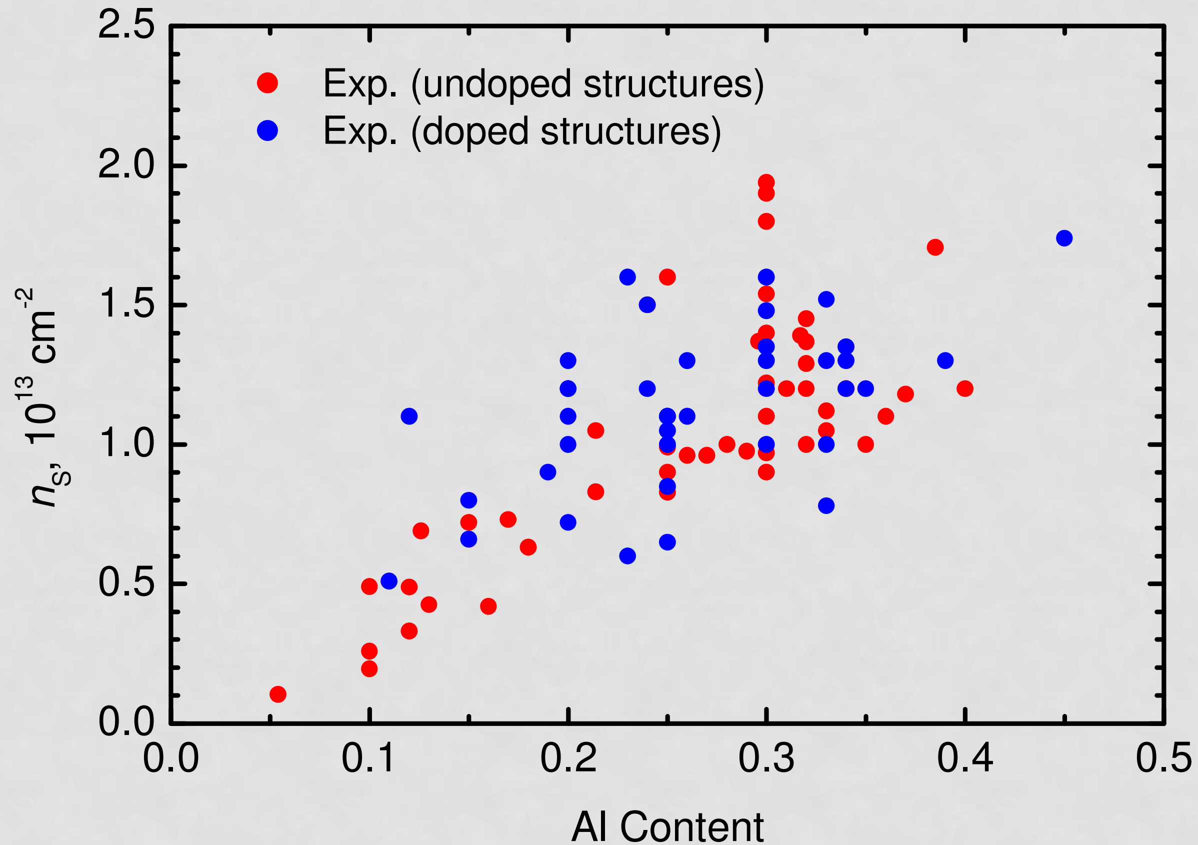

**At the AlGaN/GaNinterface occurs a positive net charge + $\sigma$ leading to the formation of a 2DEG in the GaN.**

**Two important messages:**

- **Only a small portion of the 2DEG elecrons is caused by the barrier doping !**
- **Even without any doping very high 2DEG sheet concentrations are possible!**

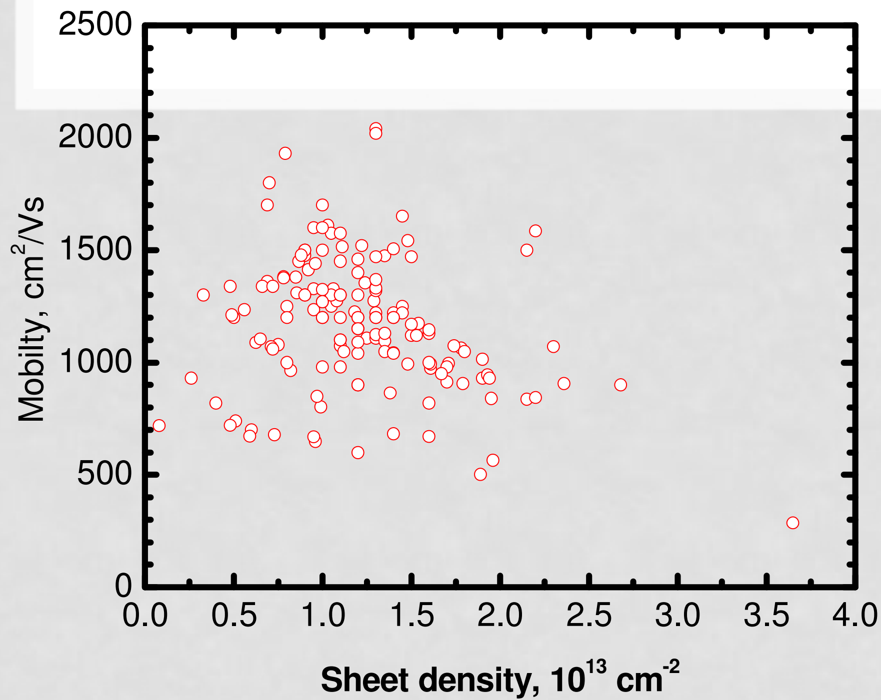


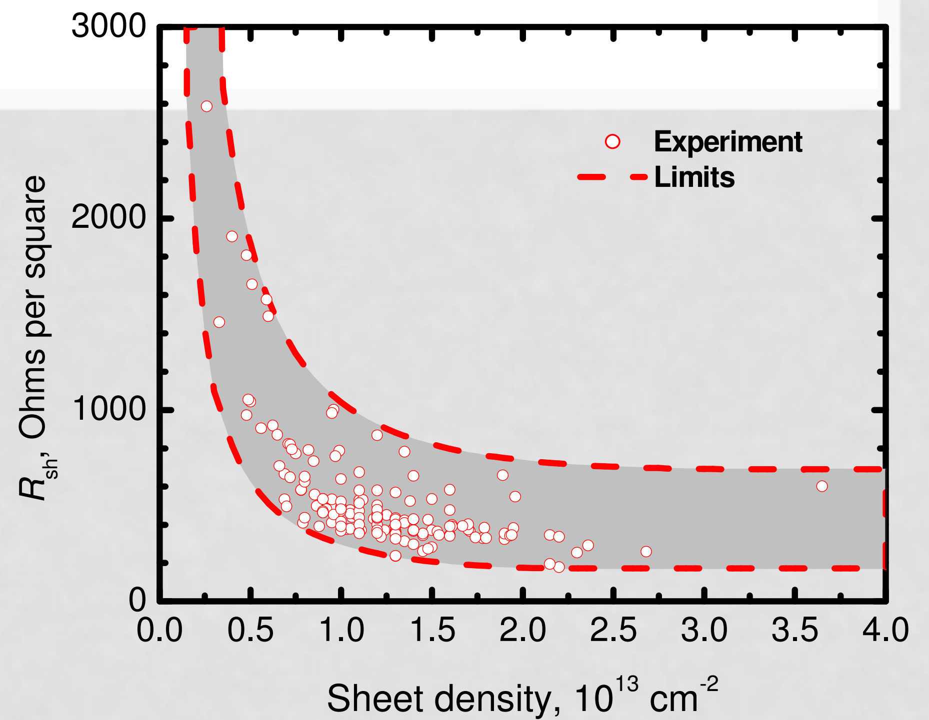
# 2DEGs in AlGaN/GaN Structures




**Measured 2DEG sheet concentration $n_S$ in $Al_xGa_{1-x}N/GaN$ heterostructures vs. Al content $x$**

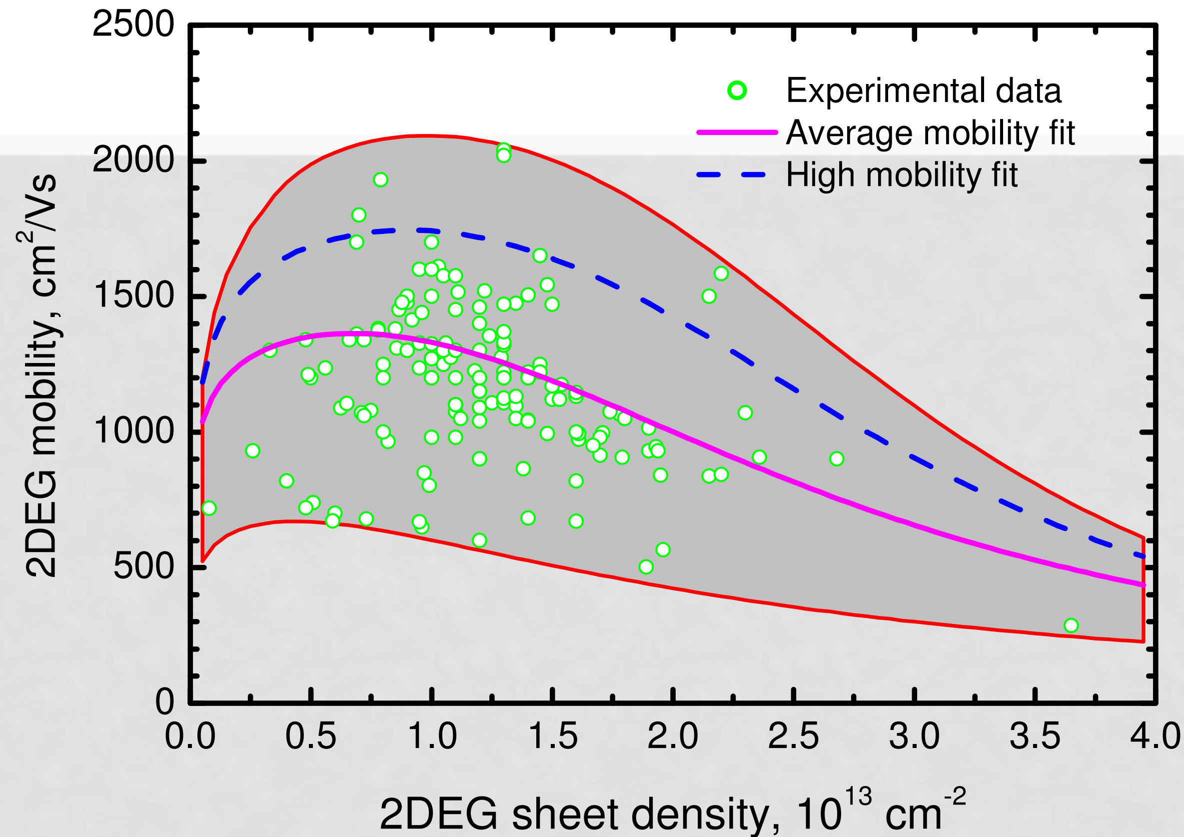
# Carrier Transport in AlGaN/GaN 2DEGs




$$R_{sh} = \frac{1}{q\ \mu_0\ n_S}$$

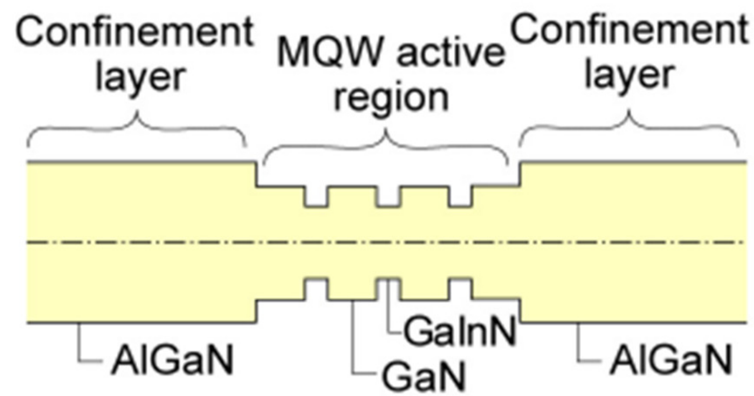
# Carrier Transport in 2DEGs

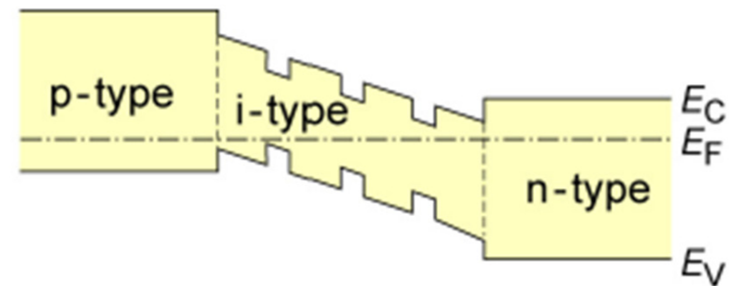



**2DEG Low-Field Mobility in AlGaN/GaN vs. Sheet concentration**

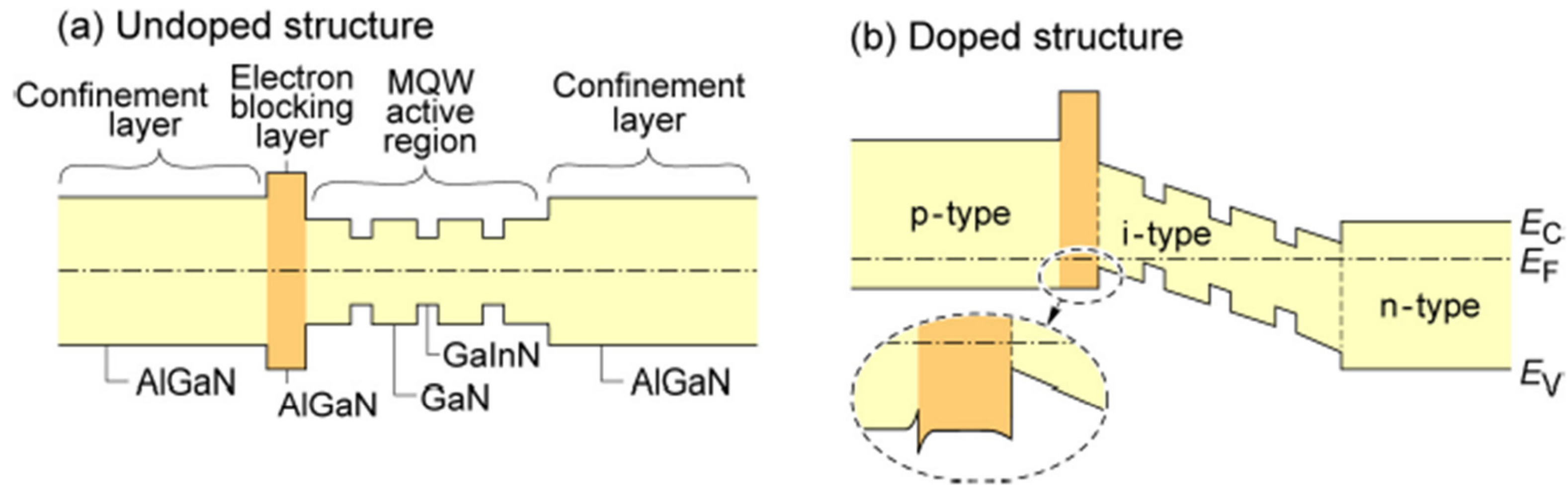
**Note: $\mu_0$ in GaN bulk ($n$ = $10^{17}$ $cm^{-3}$) is about 700 $cm^2/Vs$**

Band diagram of AlGaN / GaN / GaInN 3 QW LED:



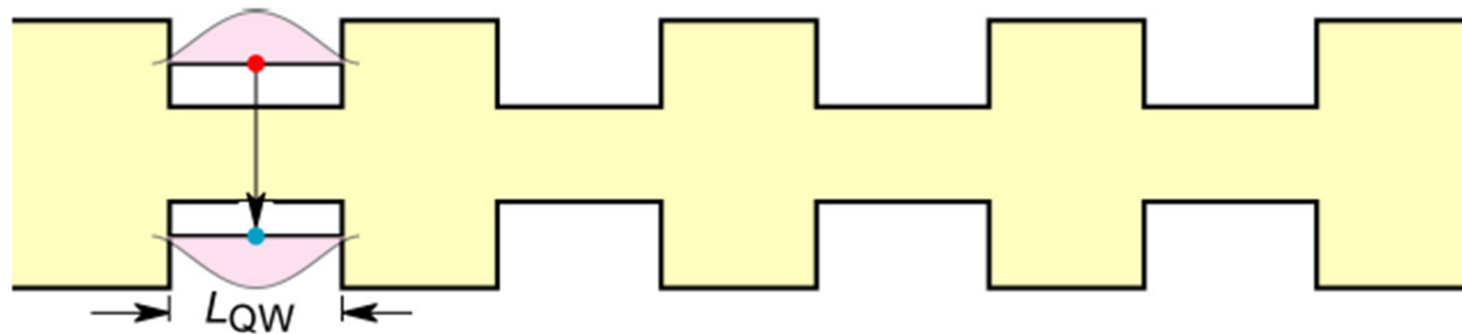
## Current blocking layers:




AlGaN current-blocking layer in an AlGaN/GaN/GaInN multi-quantum well LED structure. (a) Band diagram without doping. (b) Band diagram with doping. The Al content in the electron-blocking layer is higher than in the p-type confinement layer.

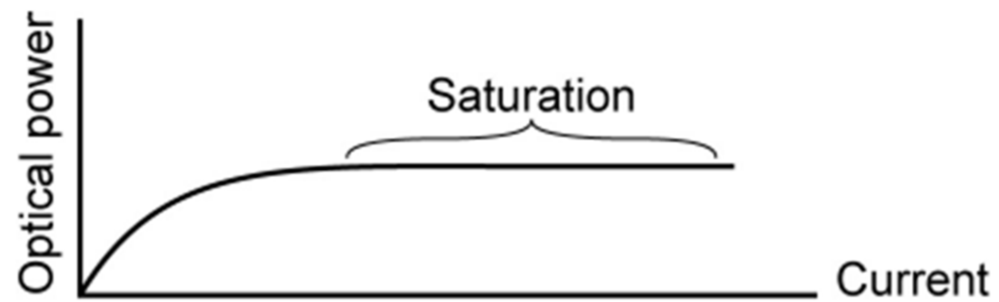
# Multiple quantum wells (MQW)

Band diagram:

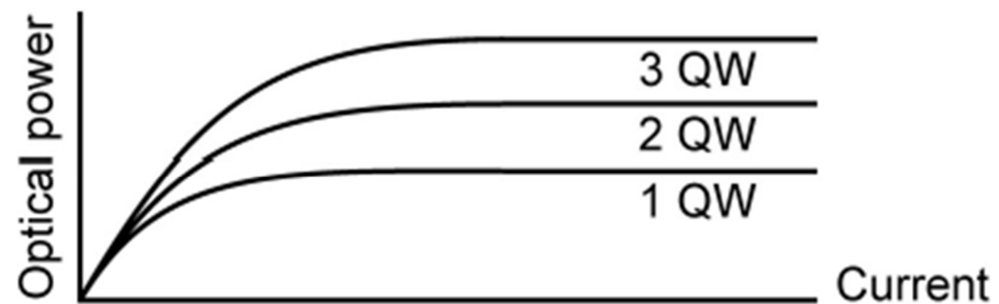



- A MQW structure has more than one well, that is more carriers can be accommodated.
- Single quantum well (SQW) structures have a problem: Band filling. If a QW is filled with carriers, luminescence saturation occurs at high current densities.

Light output characteristic of SQW LED:




Solution: MQW structures:



# EXAMPLE 1 – SINGLE QUANTUM WELL BLUE GAN LED

# SILVACO PROGRAM INPUT DECK

```
go atlas
#
# 2 Core multi-thread simulation
#
# GaN LED Opto Device Simulation
# Silvaco International 2004, 2007
#
# Requires : ATLAS/BLAZE/QUANTUM/LED

# Blue single-quantum well LED

# Band offset
# dEc:dEv(GaN:InGaN)=0.7:0.3
# dEc:dEv(AlGaN:GaN)=0.7:0.3
#
```

```
# Parameter used for this blue SQW LED
######################################################
#######################
#  Epilayer #  Material  #  Type  # Thickness #  Doping   #    Mobility    #
#           #            # p or n #    [nm]   #  [cm-3]   #   [cm2/V-s]   #
######################################################
#######################
# p-Contact #    GaN     #    p   #    500    #    1e19   #       10      #
# p-Emitter #  Al0.2GaN  #    p   #    100    #    1e19   #       10      #
#   Blue    #  In0.2GaN  #    -   #     3     #     -     #      100      #
# n-Contact #    GaN     #    n   #   4000    #    1e18   #      100      #
# n-Buffer  #    GaN     #    -   #    30     #     -     #      100      #
######################################################
#######################

#---------------------------------------------------------------
# SECTION 1 : MESH GENERATION
#---------------------------------------------------------------
#
# 1 Dimensional Structure
# for A/cm^2 Unit
mesh width=1e8
```

```
x.mesh  loc=0.0 spac=0.5
x.mesh  loc=1.0 spac=0.5
#
y.mesh  loc=0.0 spac=0.1
y.mesh  loc=0.5 spac=0.001
y.mesh loc=0.55 spac=0.005
y.mesh  loc=0.600 spac=0.0002
y.mesh  loc=0.603 spac=0.0002
y.mesh loc=0.65 spac=0.005
y.mesh  loc=5.00   spac=1.0
#
#------------------------------------------------------------
# SECTION 2: REGIONS AND ELECTRODES
#------------------------------------------------------------
region num=1 material=GaN y.max=0.5
region num=2 material=AlGaN y.min=0.5 y.max=0.6 x.comp=0.2
region num=3 material=InGaN y.min=0.6 y.max=0.603 x.comp=0.20 name=well \
      qwell led calc.strain polarization polar.scale=1.0 well.ny=50
region num=4 material=GaN y.min=0.603 substrate
#
electrode name=anode   top
electrode name=cathode bottom
```

```
#-------------------------------------------------------------
# SECTION 3: DOPING PROFILES
#-------------------------------------------------------------
# p type is Mg
# n type is Si
doping region=1 uniform p.type conc=1e19
doping region=2 uniform p.type conc=1e19
doping region=4 uniform n.type conc=1e18
#
#---------------------------------------------------------------
# SECTION 4: MATERIAL MODELS
#---------------------------------------------------------------
#
material material=GaN taun0=1e-9 taup0=1e-9 copt=1.1e-8 \
        augn=1.0e-34 augp=1.0e-34
material material=AlGaN taun0=1e-9 taup0=1e-9 copt=1.1e-8 \
        augn=1.0e-34 augp=1.0e-34
material material=InGaN taun0=1e-9 taup0=1e-9 copt=1.1e-8 \
        augn=1.0e-34 augp=1.0e-34
#
```

```
# Lorentz Broaden factor
material well.gamma0=30e-3
#
material edb=0.080 eab=0.101
#
models k.p fermi incomplete consrh auger optr print
models region=3 k.p chuang spontaneous lorentz
#
mobility mun0=100 mup0=10
#
#-----------------------------------------------------------------
# SECTION 5: OUTPUT FLAGS and METHOD
#-----------------------------------------------------------------
#
output con.band val.band band.param charge polar.charge e.mobility \
      h.mobility u.srh u.radiative u.auger permi
#
method climit=1e-4 maxtrap=10
#
```

```
#-------------------------------------------------------------------
# SECTION 6: INITIAL SOLUTION
#-------------------------------------------------------------------
#
solve init
solve prev
#
save outf=ledex01_1.str
#
#--------------------------------------------------------------------
# SECTION 7: BIAS RAMP and Save the SPECTRUM
#--------------------------------------------------------------------
#
probe name=Recombination integrate recomb
probe name=Radiative integrate radiative rname=well
#
log outf=ledex01.log
solve vstep=0.05 vfinal=3.5 name=anode
save outf=ledex01_3p5.str
save spectrum=ledex01_3p5.spc lmin=0.40 lmax=0.50 nsamp=100
```

```
solve vstep=0.05 vfinal=4.0 name=anode
save outf=ledex01_4p0.str
save spectrum=ledex01_4p0.spc lmin=0.40 lmax=0.50 nsamp=100

solve vstep=0.05 vfinal=5.0 name=anode
save outf=ledex01_5p0.str
save spectrum=ledex01_5p0.spc lmin=0.40 lmax=0.50 nsamp=100
#
#-------------------------------------------------------------
# SECTION 8: PLOTTING CURVES
#-------------------------------------------------------------
#
# V-I Curve
tonyplot ledex01.log    -set ledex01_0.set
# I-L Curve
tonyplot ledex01.log    -set ledex01_1.set
# EL Intensity at 3.5V, 4.0V and 5.0V
tonyplot -overlay ledex01_3p5.spc ledex01_4p0.spc ledex01_5p0.spc -set
ledex01_2.set
```

```
extract init infile="ledex01_3p5.str"
extract name="Electron" curve(depth,impurity="Electron Conc" material="All" \
      x.val=0.5) outfile="ledex01_3p5_Electron.dat"
extract name="Electron" curve(depth,impurity="Hole Conc" material="All" \
      x.val=0.5) outfile="ledex01_3p5_Hole.dat"

extract init infile="ledex01_4p0.str"
extract name="Electron" curve(depth,impurity="Electron Conc" material="All" \
      x.val=0.5) outfile="ledex01_4p0_Electron.dat"
extract name="Electron" curve(depth,impurity="Hole Conc" material="All" \
      x.val=0.5) outfile="ledex01_4p0_Hole.dat"

extract init infile="ledex01_5p0.str"
extract name="Electron" curve(depth,impurity="Electron Conc" material="All" \
      x.val=0.5) outfile="ledex01_5p0_Electron.dat"
extract name="Electron" curve(depth,impurity="Hole Conc" material="All" \
      x.val=0.5) outfile="ledex01_5p0_Hole.dat"

tonyplot -overlay ledex01_3p5_Electron.dat ledex01_3p5_Hole.dat
ledex01_4p0_Electron.dat ledex01_4p0_Hole.dat ledex01_5p0_Electron.dat
ledex01_5p0_Hole.dat -set ledex01_3.set
quit
```

# CHARACTERISTIC SILVACO STATEMENTS

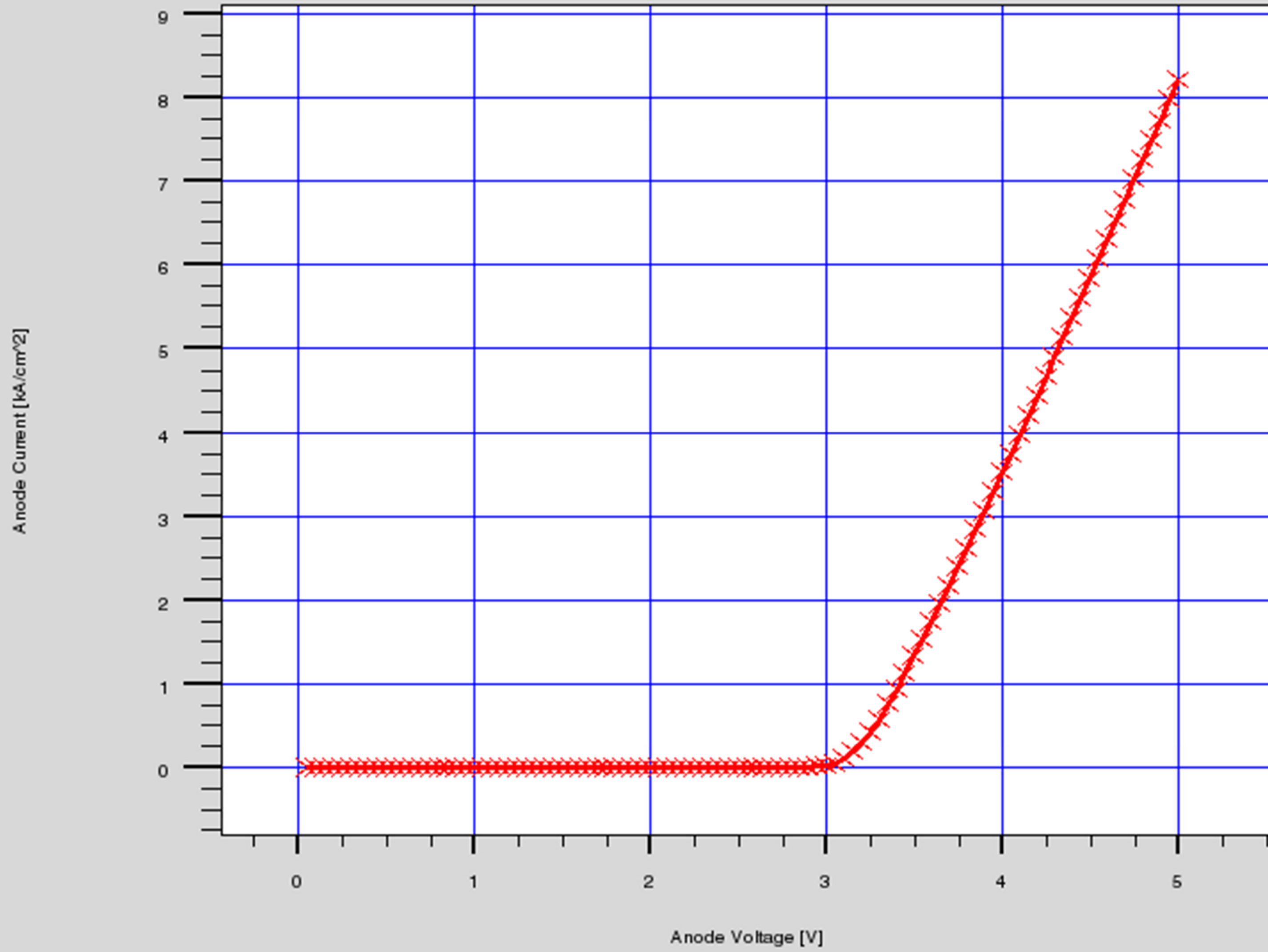
- Strain definition ➔ REGION STATEMENT

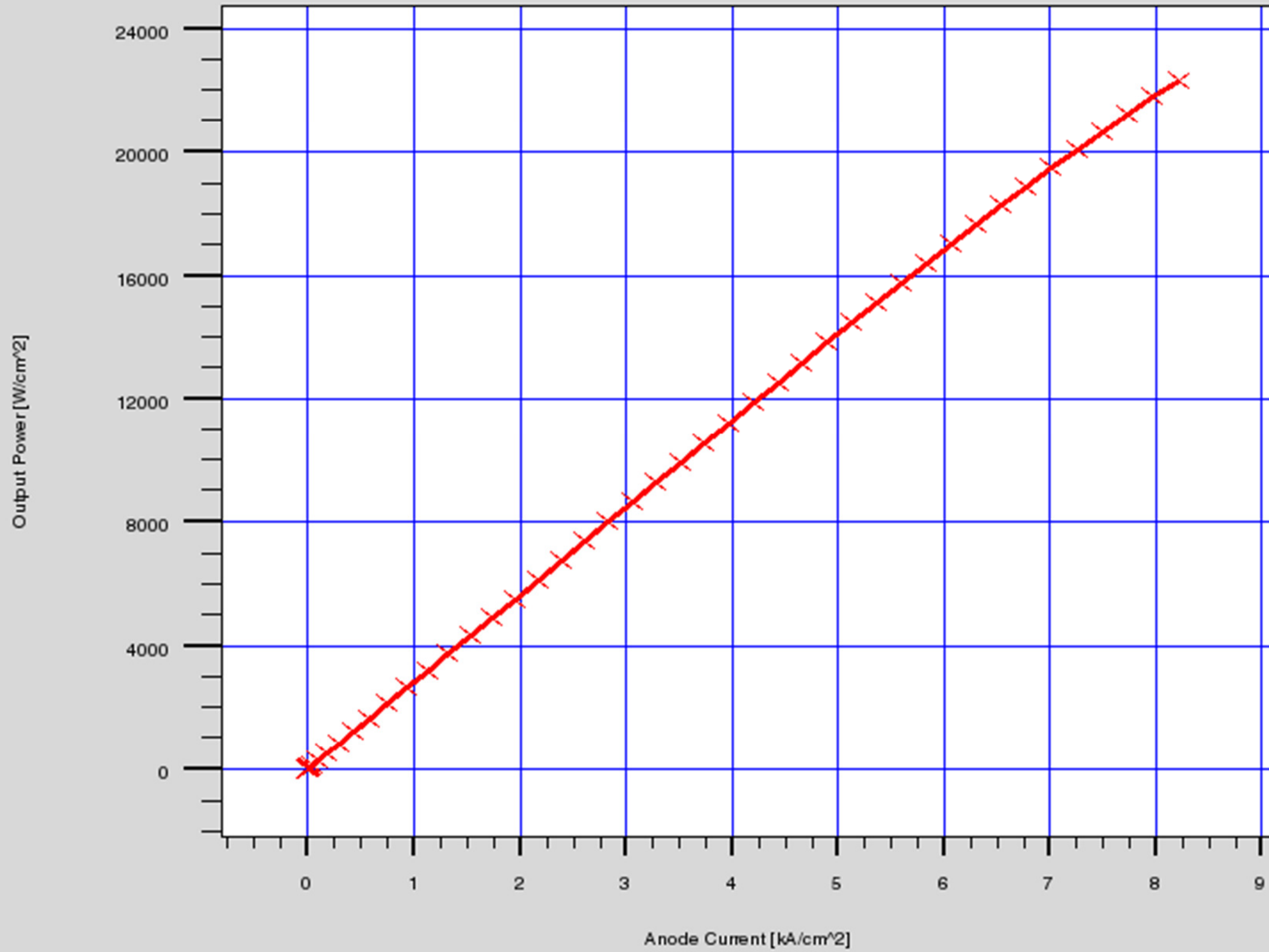
CALC.STRAIN, POLAR.SCALE, POLARIZATION

- Broadening ➔ LORENTZ, CHUANG, SPONTANEOUS

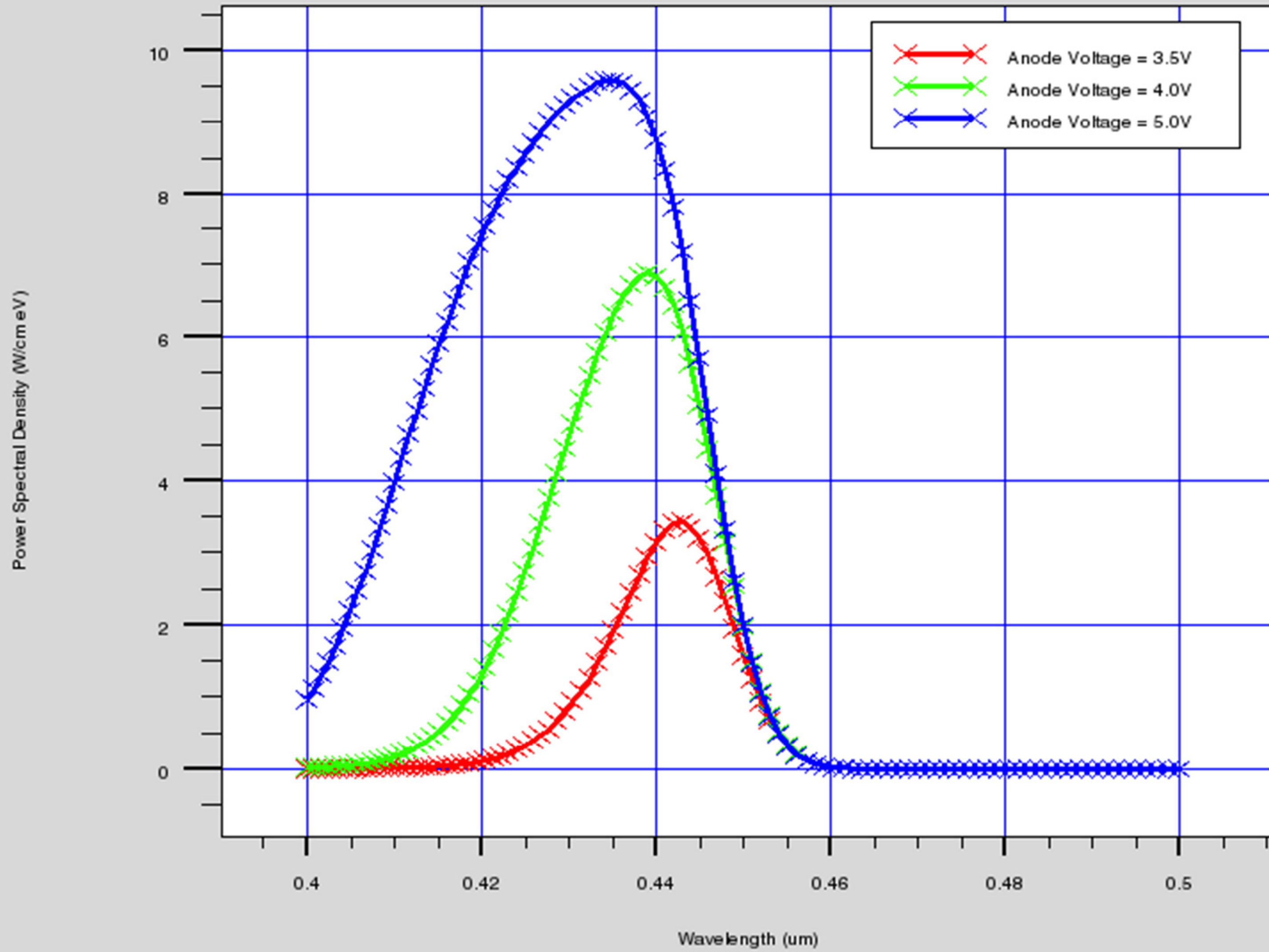
- k.p model ➔ BAND PARAMETERS

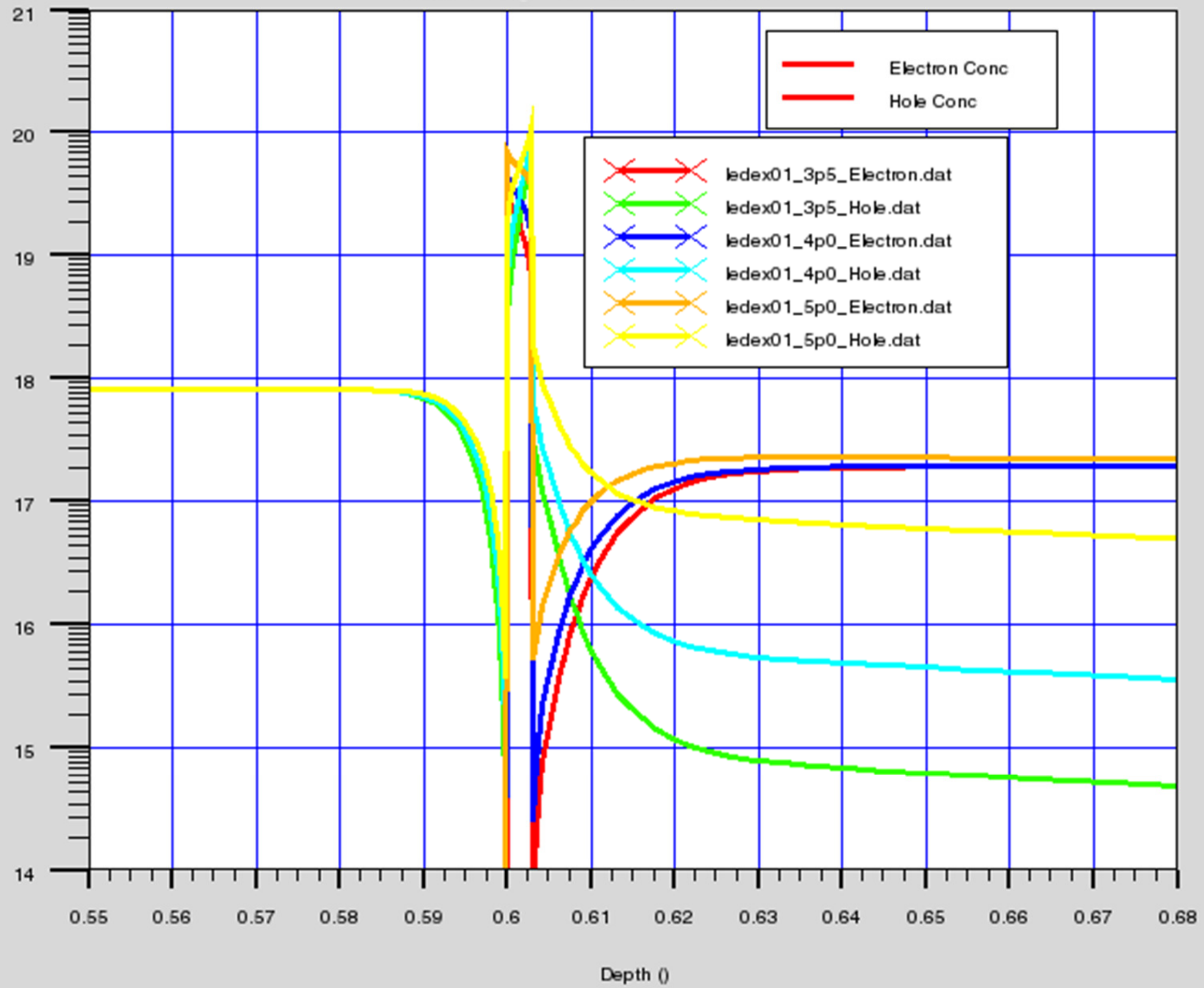
- To get the photoluminescence spectra ➔ QWELL and LED have to be specified under the region statement


ATLAS/BLAZE/QUANTUM/LED
Blue SQW LED V-J Curve
Anode Current [kA/cm^2]
Anode Voltage [V]
0
1
2
3
4
5
6
7
8
9



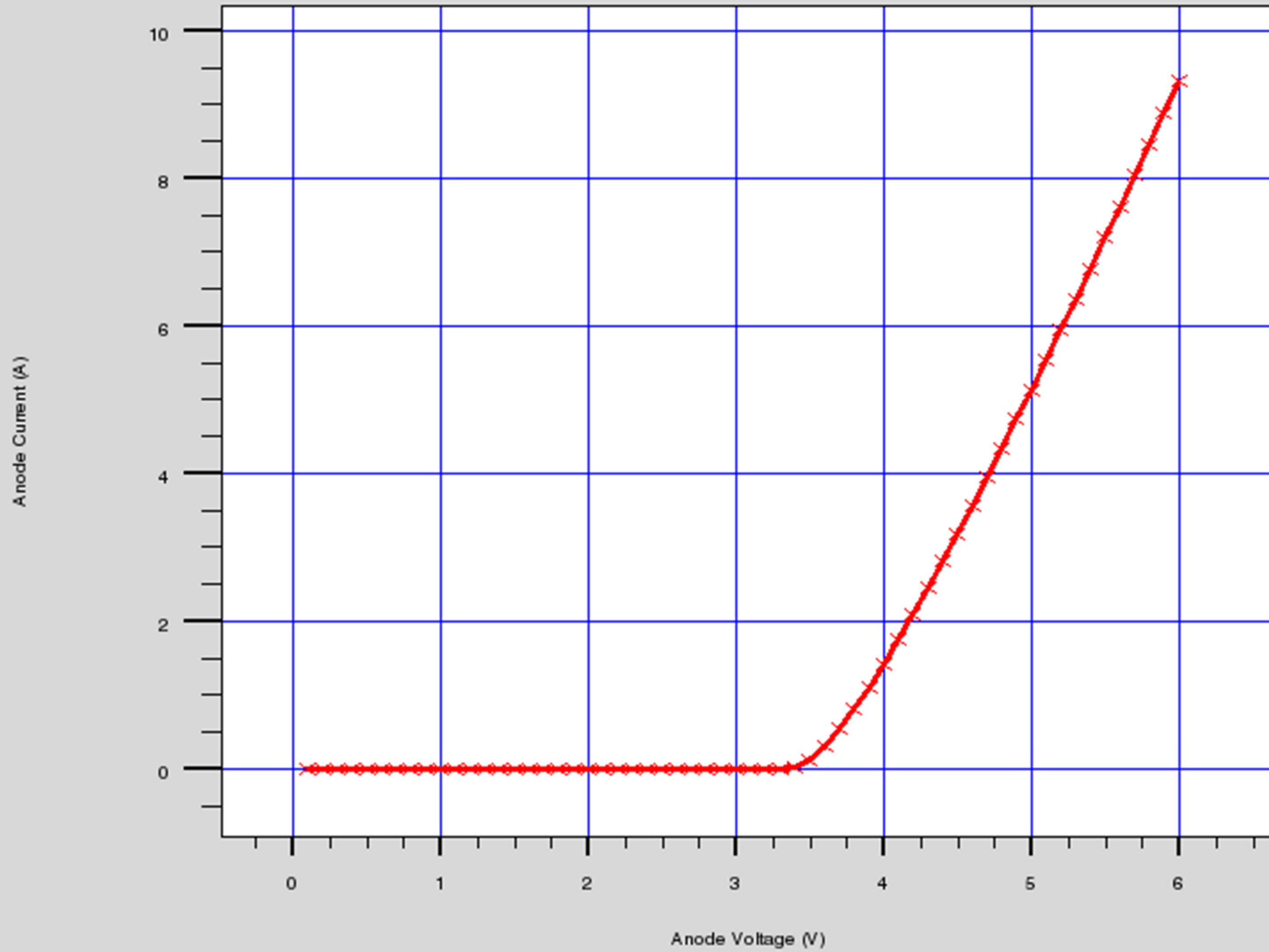
ATLAS/BLAZE/QUANTUM/LED
Blue SQW LED J-L Curve at R.T
Output Power [W/cm^2]
24000
20000
16000
12000
8000
4000
0
0
1
2
3
4
5
6
7
8
9
Anode Current [kA/cm^2]

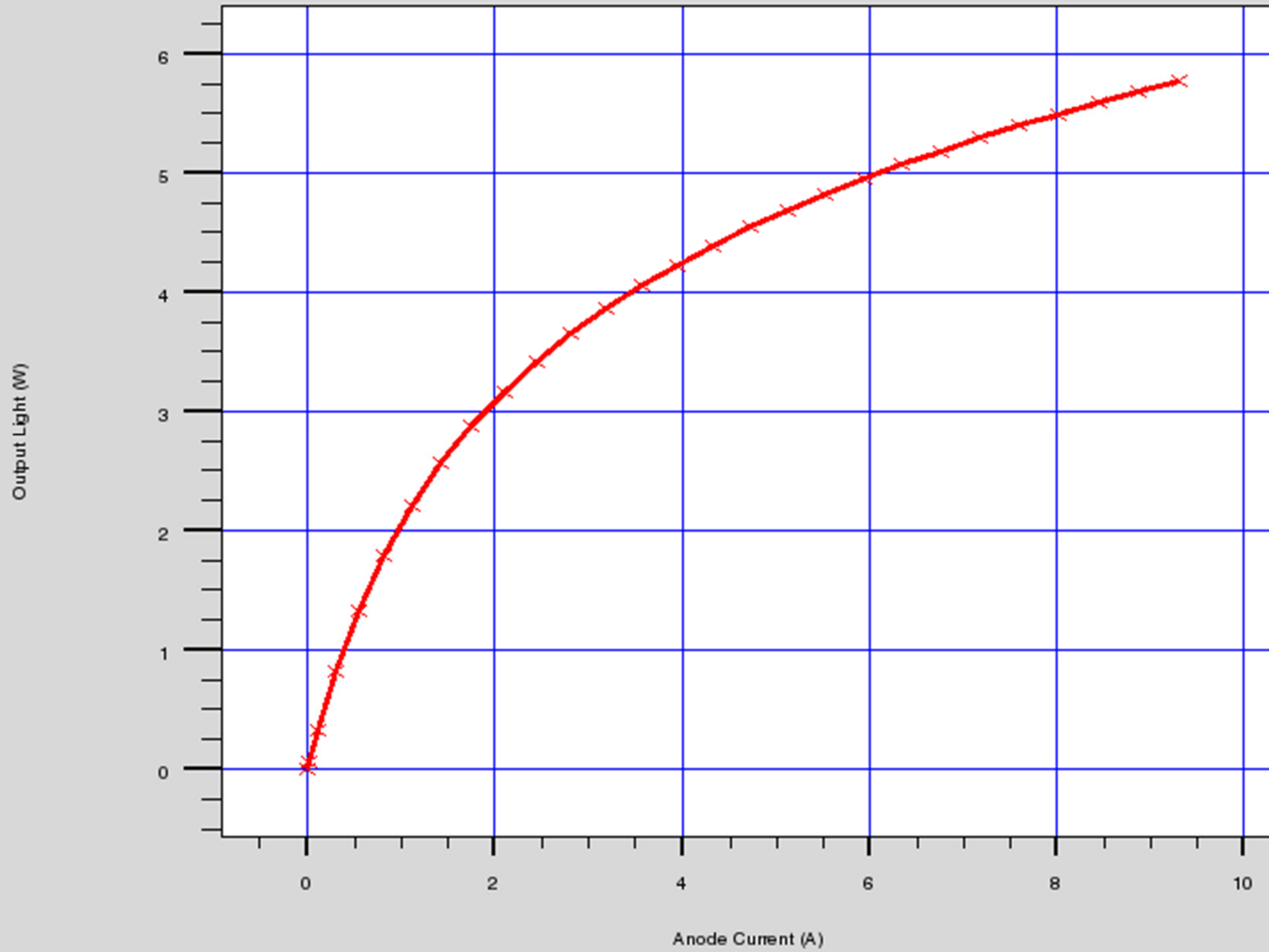

ATLAS/BLAZE/QUANTUM/LED
Electroluminescence of Blue SQW LED
Anode Voltage = 3.5V
Anode Voltage = 4.0V
Anode Voltage = 5.0V
Power Spectral Density (W/cm eV)
Wavelength (um)
10
8
6
4
2
0
0.4
0.42
0.44
0.46
0.48
0.5

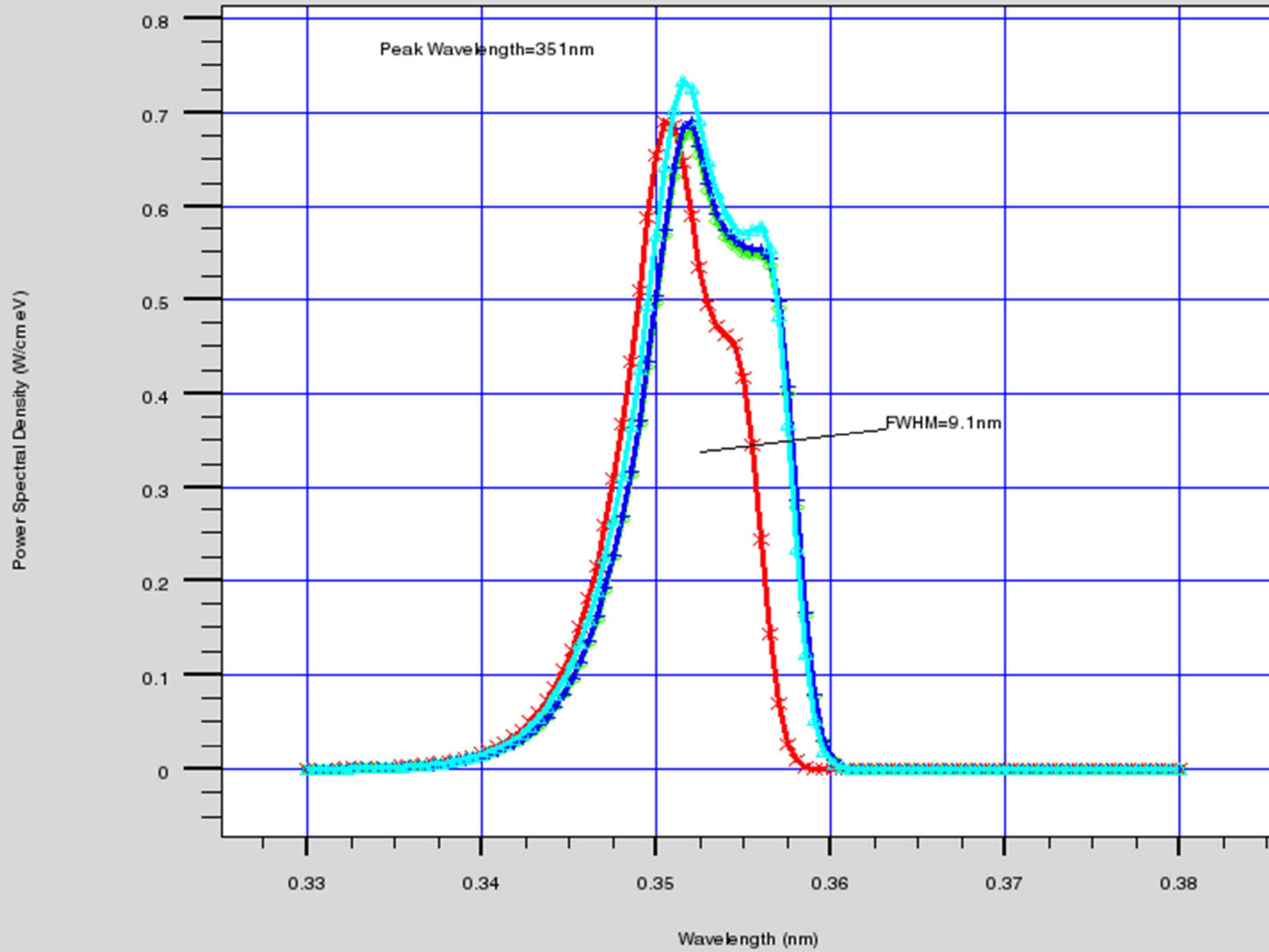


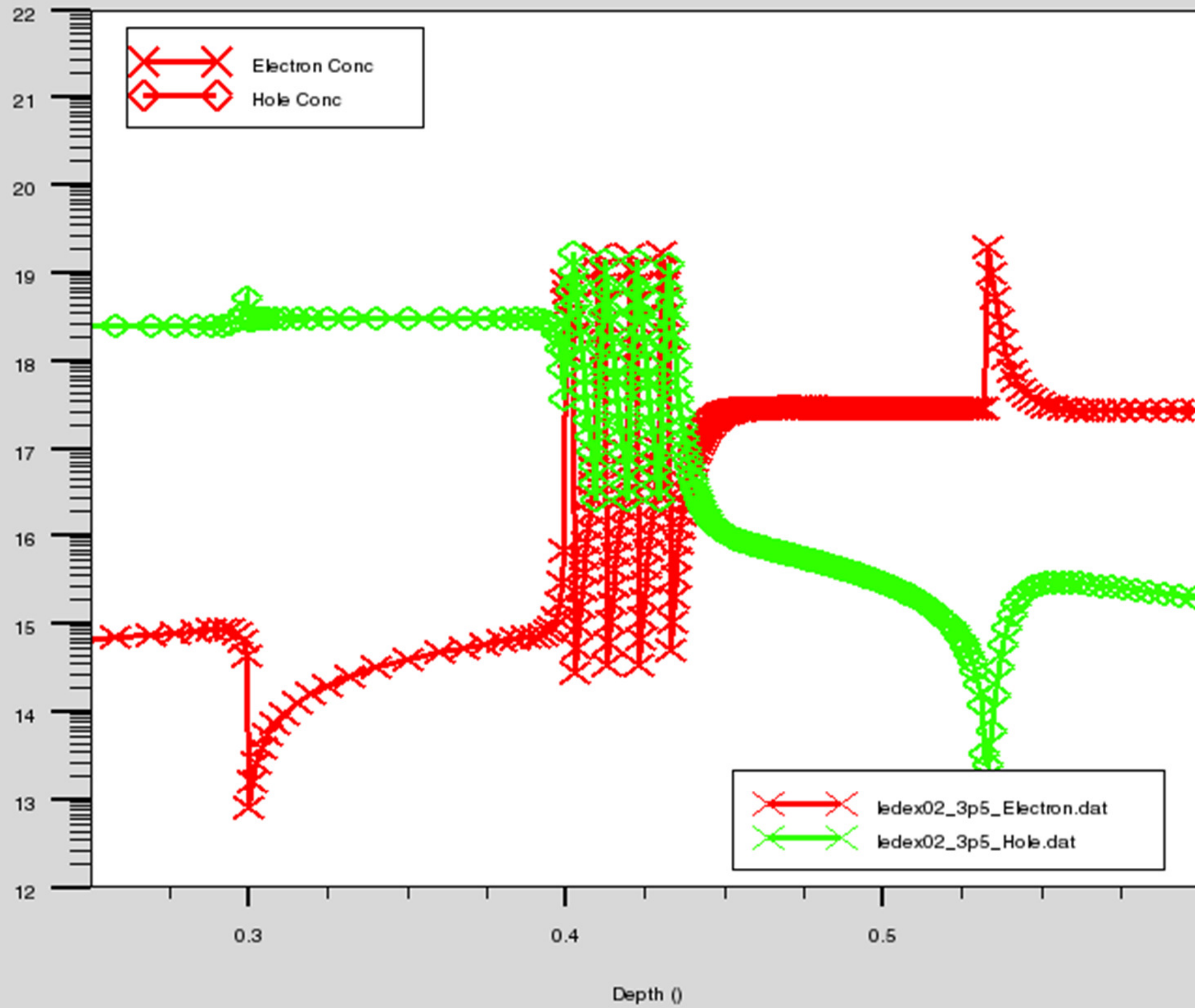
Electron and Hole Concentration
Anode Voltage is 3.5V, 4.0V and 5.0V
Electron Conc
Hole Conc
ledex01_3p5_Electron.dat
ledex01_3p5_Hole.dat
ledex01_4p0_Electron.dat
ledex01_4p0_Hole.dat
ledex01_5p0_Electron.dat
ledex01_5p0_Hole.dat
21
20
19
18
17
16
15
14
0.55
0.56
0.57
0.58
0.59
0.6
0.61
0.62
0.63
0.64
0.65
0.66
0.67
0.68
Depth ()

# EXAMPLE 2 – MULTIPLE QUANTUM WELL UV LED

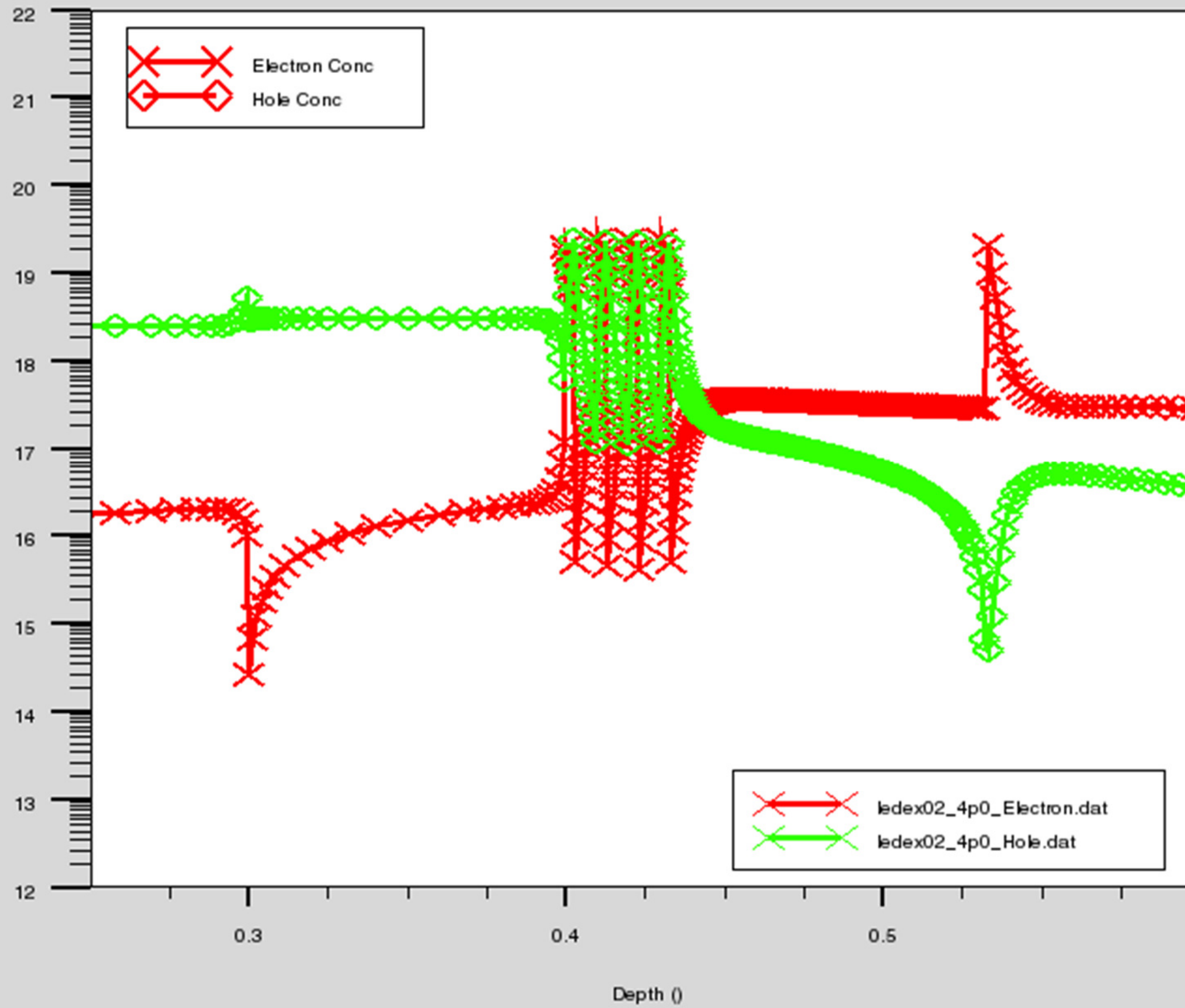

ATLAS/BLAZE/QUANTUM/LED
U-V MQW LED I-V Curve
Anode Current (A)
10
8
6
4
2
0
0
1
2
3
4
5
6
Anode Voltage (V)


ATLAS/BLAZE/QUANTUM/LED
U-V MQW LED I-L Curve
Output Light (W)
Anode Current (A)
0
1
2
3
4
5
6
0
2
4
6
8
10

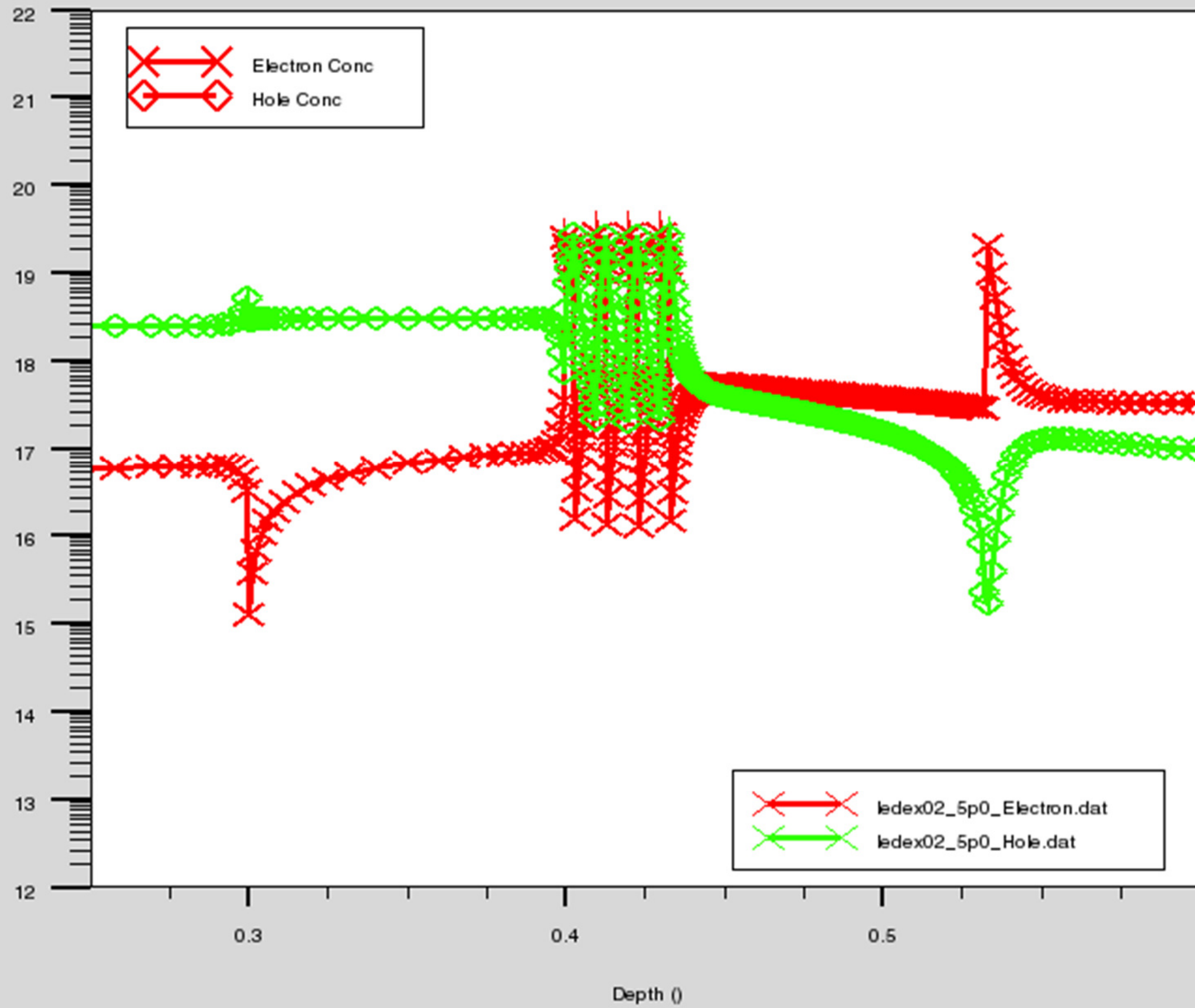

ATLAS/BLAZE/QUANTUM/LED
EL Spectrum at 3.5V R.T
Peak Wavelength=351nm
FWHM=9.1nm
Power Spectral Density (W/cm eV)
Wavelength (nm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.33
0.34
0.35
0.36
0.37
0.38



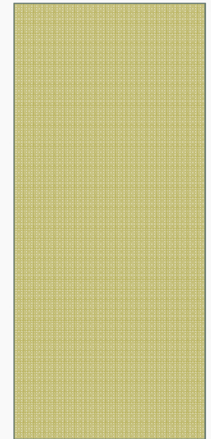
Electron and Hole Conc. at Anode Voltage=3.5V
Electron Conc
Hole Conc
ledex02_3p5_Electron.dat
ledex02_3p5_Hole.dat
22
21
20
19
18
17
16
15
14
13
12
0.3
0.4
0.5
Depth ()



Electron and Hole Conc. at Anode Voltage=4.0V
Electron Conc
Hole Conc
ledex02_4p0_Electron.dat
ledex02_4p0_Hole.dat
22
21
20
19
18
17
16
15
14
13
12
0.3
0.4
0.5
Depth ()


Electron and Hole Conc. at Anode Voltage=5.0V
22
21
20
19
18
17
16
15
14
13
12
Electron Conc
Hole Conc
ledex02_5p0_Electron.dat
ledex02_5p0_Hole.dat
0.3
0.4
0.5
Depth ()

# SELF-HEATING EFFECTS IN LEDS



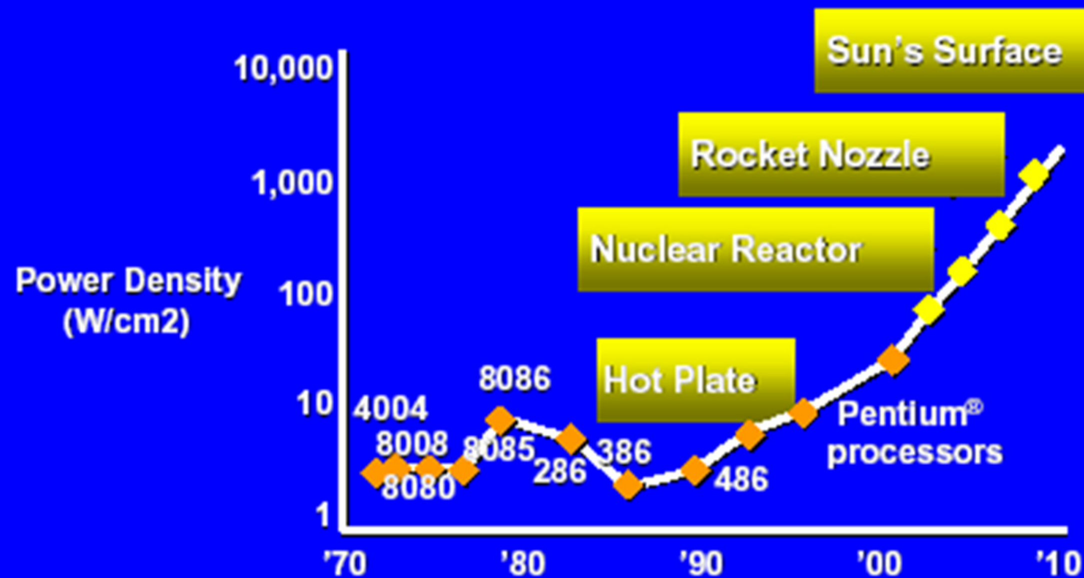
# OUTLINE

- Modeling self-heating effects with Silvaco
- Example 3: Self-heating effects in LEDs

# MODELING SELF-HEATING EFFECTS WITH SILVACO

DRAGICA VASILESKA

# IS SELF-HEATING IMPORTANT?



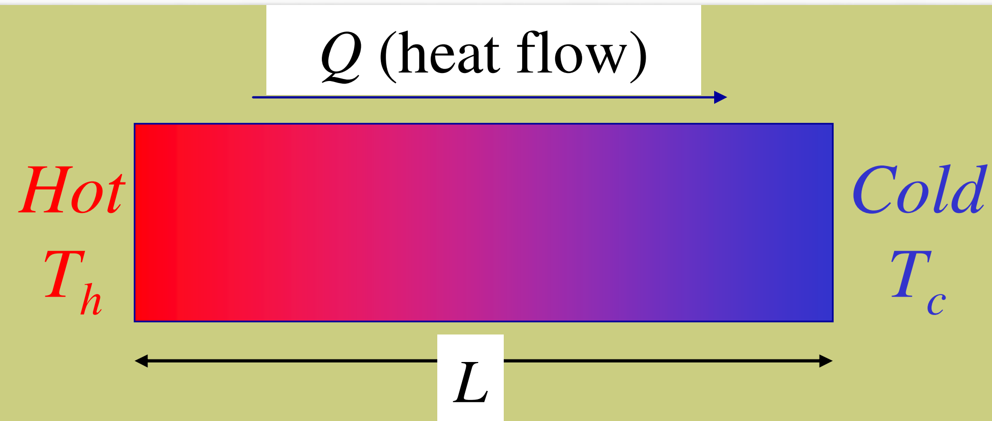
# HEATING VS. DEVICE PERFORMANCE

- In most cases heat degrades device performance because it degrades carrier mobility and, therefore, the on-state current, i.e. the transistor drive.
- Heating is severely degrading mechanism in SOI device technology due to the low thermal conductivity of the underlying $SiO_2$ box layer.
- In both conventional MOSFET devices and SOI devices heating increases the breakdown voltage of the transistor.
- Heating is most simplistically modeled with a Fourier law.

# APPROXIMATIONS MADE IN SILVACO

- **Low field transport =>**
    - Electron temperature equals the lattice temperature (no self-heating)
    - Dominant scattering mechanism at low electric fields is acoustic phonon scattering (isotropic, therefore very effective in randomization of the mobility)
    - Energy balance equation for acoustic phonons reduces to simple Joule heating conduction equation

# LATTICE HEATING – FOURIER LAW




$$Q = kA\frac{T_h - T_c}{L} = kA\frac{dT}{dx}$$

**Thermal conductivity**

# SPECIFIC THERMAL ENERGY VS. TEMPERATURE

$$\frac{\partial e}{\partial t} = c\frac{\partial T}{\partial t} \tag{4}$$

where $c = c(\boldsymbol{x}, t)$ is the **thermal capacity** $\left[\frac{\mathrm{J}}{\mathrm{kg \cdot K}}\right]$.

- The thermal capacity is also called *specific heat capacity* (or simply, *specific heat*).
- It describes the ability of a material to store the heat and refers to the quantity that represents the amount of heat required to change the temperature of one unit of mass by one degree.

# DERIVATION OF THE HEAT DIFFUSION EQUATION

Energy vs. temp.

$$\frac{\partial e}{\partial t} = c\,\frac{\partial T}{\partial t}$$

Energy conservation law

$$\varrho\,\frac{\partial e}{\partial t} + \nabla\cdot\boldsymbol{q} = f$$

Fourier's law

$$\boldsymbol{q} = -k\nabla T$$

**Heat conduction equation**

$$\varrho c\,\frac{\partial T}{\partial t} - \nabla\cdot(k\nabla T) = f$$

where the only unknown is the temperature: $T(\boldsymbol{x},t) = ?$

# HEAT DIFFUSION EQUATION

1st law (energy conservation)→

Heat conduction = Rate of change of energy storage

$$k\frac{\partial^2 T}{\partial^2 x} = C\frac{\partial T}{\partial t}$$

Specific heat

•Conditions:

$t >> \tau \equiv$ scattering mean free time of energy carriers

$L >> l \equiv$ scattering mean free path of energy carriers

•Breaks down for applications involving thermal transport in small length/ time scales, e.g. nanoelectronics, nanostructures, NEMS, ultrafast laser materials processing…

# Theoretical Models implemented in Silvaco ATLAS Device Simulator

$$\nabla \cdot (\kappa \nabla T) + J \cdot E = 0$$

Temperature dependent
mobilities and diffusion coefficients

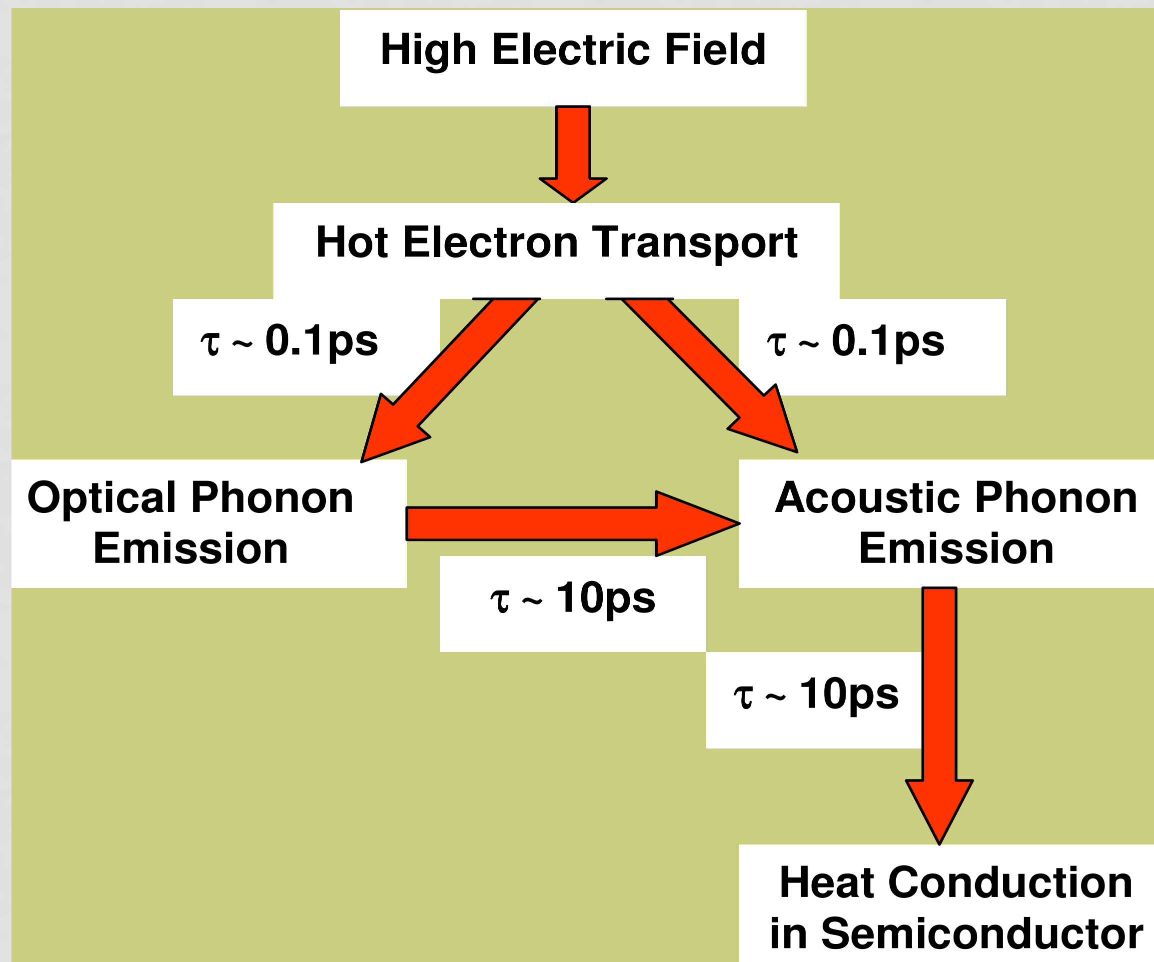
# ANALOGY TO ELECTRICAL VARIABLES

$$q = kA\frac{T_1 - T_2}{L} = \frac{T_1 - T_2}{(L/kA)}$$

$$q = \frac{\Delta T}{R_t}$$

$$i = \frac{\Delta V}{R}$$

# ENERGY TRANSFER BETWEEN THE ELECTRON BATH AND THE PHONON BATH



# ASU APPROACH TO THERMAL MODELING

$$\left(\frac{\partial}{\partial t}+v_e(\mathrm{k})\cdot\nabla_r+\frac{e}{\hbar}E(\mathrm{r})\cdot\nabla_k\right)f=\sum_{\mathrm{q}}\left\{W_{e,\mathrm{q}}^{\mathrm{k+q}\to\mathrm{k}}+W_{a,-\mathrm{q}}^{\mathrm{k+q}\to\mathrm{k}}-W_{e,-\mathrm{q}}^{\mathrm{k}\to\mathrm{k+q}}-W_{a,\mathrm{q}}^{\mathrm{k}\to\mathrm{k+q}}\right\}$$

$$\left(\frac{\partial}{\partial t}+v_p(q)\cdot\nabla_r\right)g=\sum_{\mathrm{k}}\left\{W_{e,\mathrm{q}}^{\mathrm{k+q}\to\mathrm{k}}-W_{a,\mathrm{q}}^{\mathrm{k}\to\mathrm{k+q}}\right\}+\left(\frac{\partial g}{\partial t}\right)_{p-p}$$

J. Lai and A. Majumdar, “Concurent thermal and electrical modeling of submicrometer silicon devices”, J. Appl. Phys. , Vol. 79, 7353 (1996).

$$C_{LO}\frac{\partial T_{LO}}{\partial t}=\frac{3nk_B}{2}\left(\frac{T_e-T_L}{\tau_{e-LO}}\right)+\frac{nm^*v_d^2}{2\tau_{e-LO}}-C_{LO}\left(\frac{T_{LO}-T_A}{\tau_{LO-A}}\right),$$

$$C_A\frac{\partial T_A}{\partial t}=\nabla\cdot(k_A\nabla T_A)+C_{LO}\left(\frac{T_{LO}-T_A}{\tau_{LO-A}}\right)+\frac{3nk_B}{2}\left(\frac{T_e-T_L}{\tau_{e-L}}\right).$$

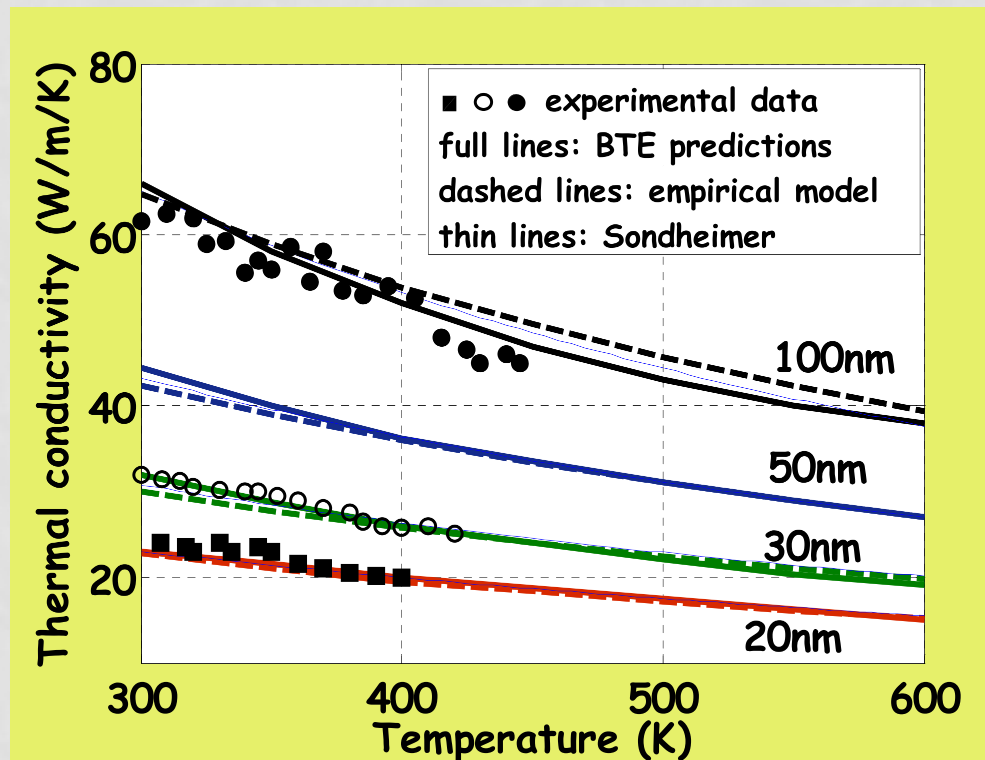
# VASILESKA CONTRIBUTION TO SILVACO MODEL

$$\kappa(z)=\kappa_0(T)\int_0^{\pi/2}\sin^3\theta\left\{1-\exp\left(-\frac{a}{2\lambda(T)\cos\theta}\right)\cosh\left(\frac{a-2z}{2\lambda(T)\cos\theta}\right)\right\}d\theta$$

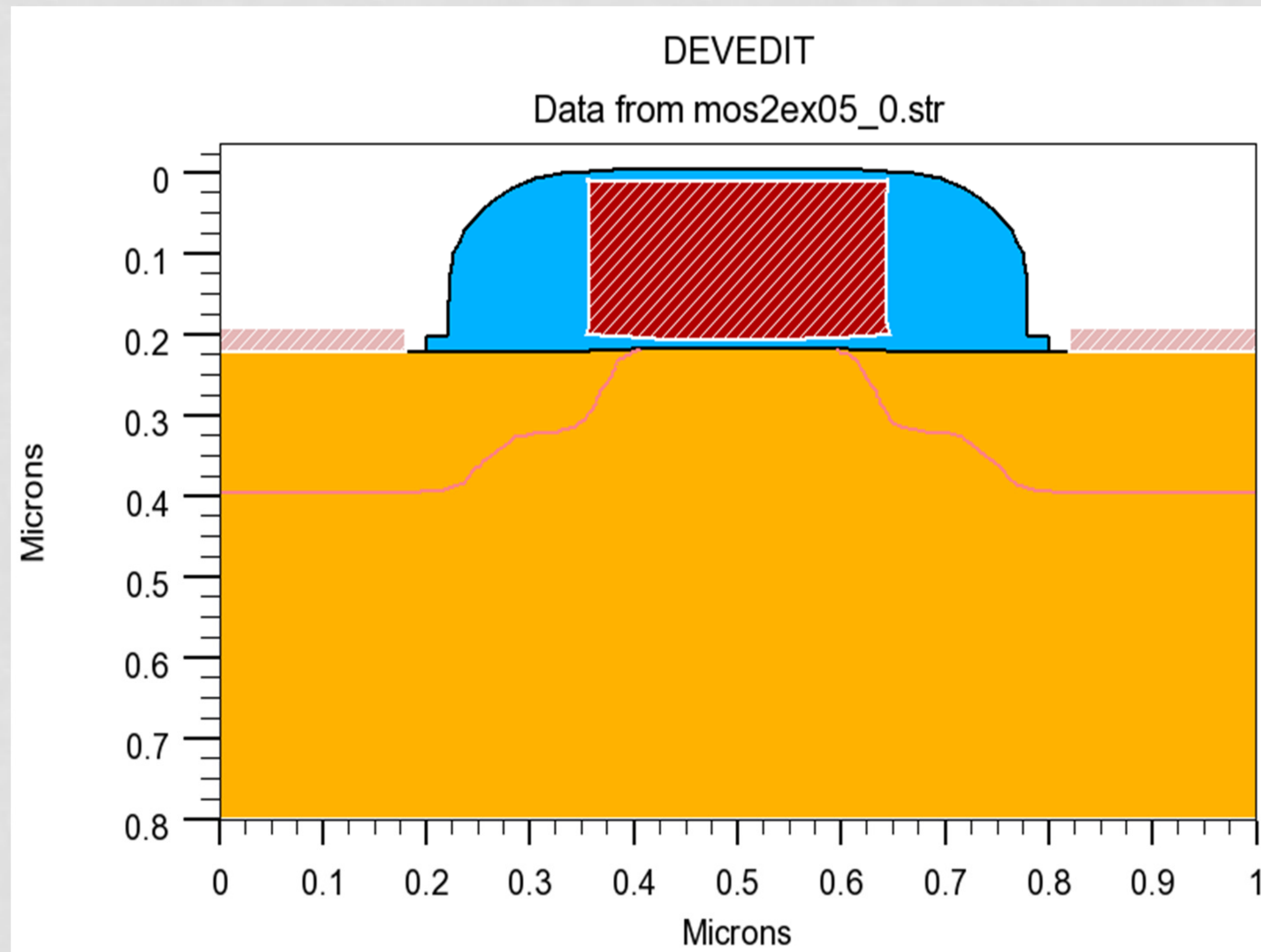
$$\lambda(T)=\lambda_0(300/T)$$

$$\kappa_0(T)=\frac{135}{a+bT+cT^2}\quad \text{W/m/K}$$

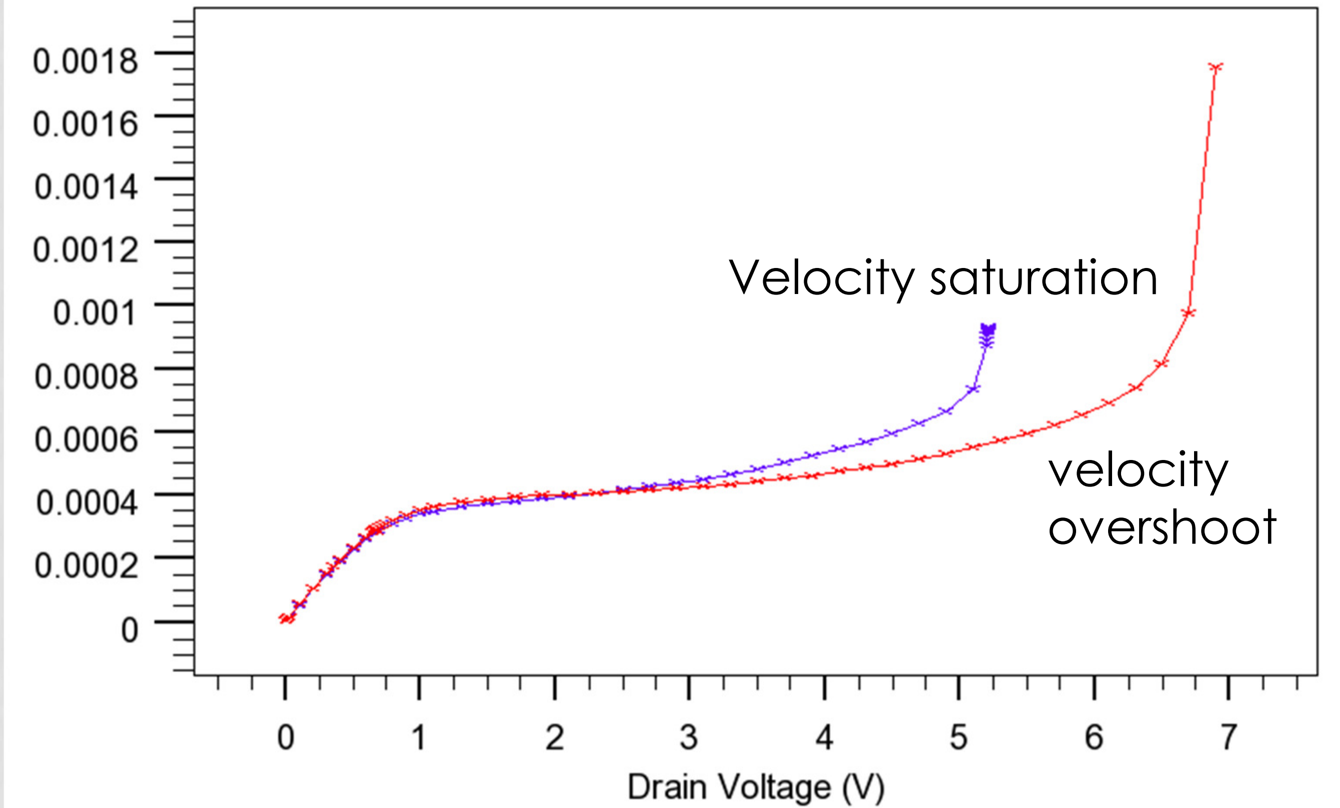
- E. H. Sondheimer, “The Mean Free Path of Electrons in Metals”, Advances in Physics, Vol. 1, no. 1, Jan. 1952, reprinted in Advances in Physics, Vol. 50, pp. 499-537, 2001.
- M. Asheghi,., M. N. Touzelbaev., K. E. Goodson, Y. K. Leung, and S. S. Wong., “Temperature Dependent Thermal Conductivity of Single-Crystal Silicon Layers in SOI Substrates,” ASME Journal of Heat Transfer, Vol.120, pp. 30-33, 1998.



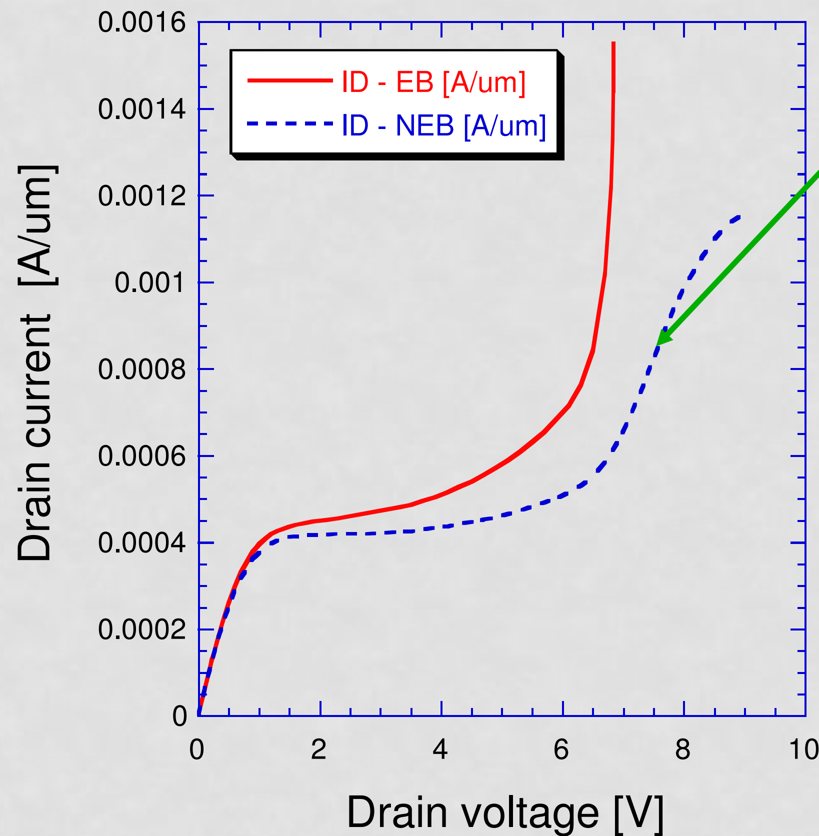
# SIMULATION EXAMPLE: CONVENTIONAL MOSFET DEVICE



# SIMULATION RESULTS: DD VS. ENERGY BALANCE

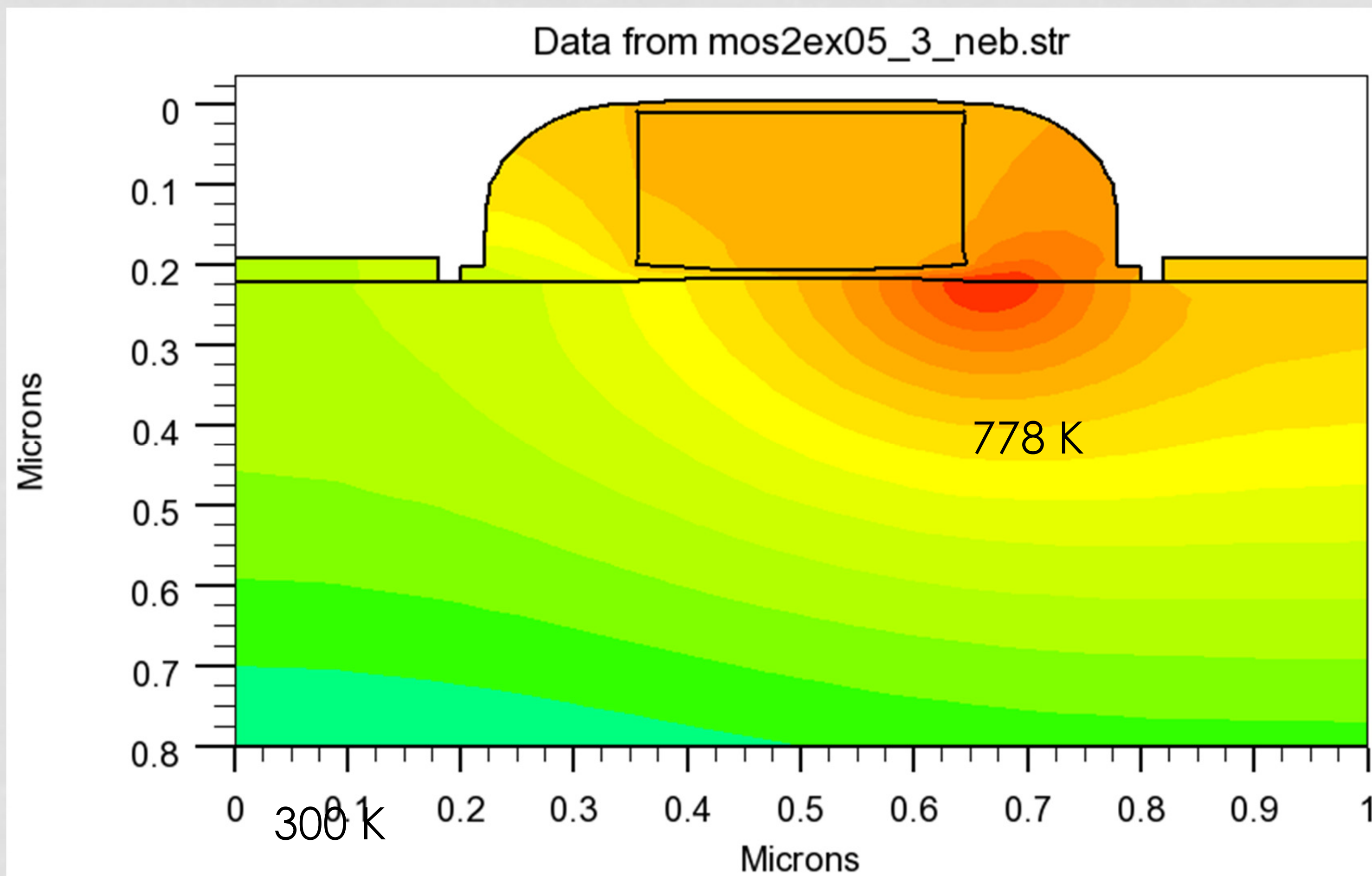


# OUTPUT CHARACTERISTICS

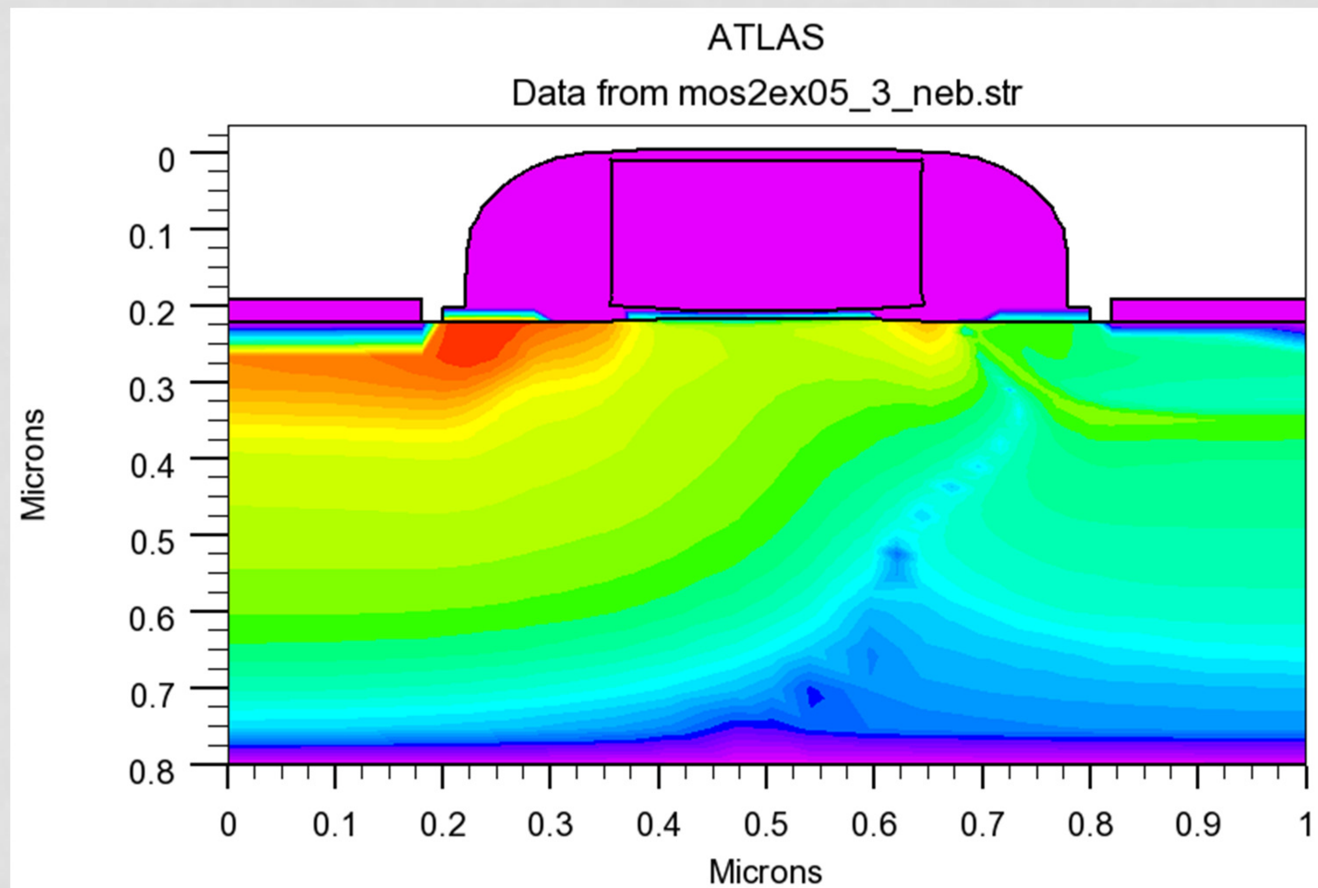



Thermal self-heating effects lead to a reduction of the *electron mobility* and *impact ionization rate* which, in turn, leads to smaller drain current.

# LATTICE TEMPERATURE



# TOTAL HEAT POWER



# INTRODUCTION OF LATTICE HEATING IN SILVACO

- Lattice heating is introduced in Silvaco in two places:
  - MODELS statement where one specifies lat.temp
  - Thermocontact

```
thermcontact num=1 x.min=0 x.max=1 y.min=0.799 \
                    y.max=0.802 alpha=3000
```

# MORE DETAILS

At least one thermal contact statement must be specified when simulating lattice heating effects

(MODELS LAT.TEMP). The THERMCONTACT statement must appear in the input deck before any METHOD statement.

**position** is a set of the position parameters described below. Either X.MIN, X.MAX, Y.MIN, and Y.MAX parameters are used to specify the exact postion of the contact or the ELEC.NUMBER parameter to specify an electrode number that the thermal contact coincides with..

**NUMBER** specifies a thermal contact number from 1 to 20. Contact numbers should be specified in increasing order. This parameters **must** be specified on all THERMCONTACT statements.

**ALPHA** specifies the reverse value of thermal resistance (a=1/RTH). This parameter may not be used if ELEC.NUMBER parameter has been specified.

# MORE DETAILS …

**EXT.TEMPER** specifies the external temperature. *Synonym*: TEMPERATURE

**Position Parameters**

**NAME** specifies which region the THERMCONTACT statement applies to. Note that the name must match the name specified in the NAME parameter of the REGION statement.

**DEVICE** specifies which device in MIXEDMODE simulation the THERMCONTACT statement applies to.

# MORE DETAILS …

**Parameter Type Default Units**
ALPHA Real W/(cm2·K)
DEVICE Character
ELEC.NUMBER Integer
EXT.TEMPER Real 300 K
NAME Character
NUMBER Integer 1
X.MAX Real Right side of structure mm
X.MIN Real Left side of structure mm
Y.MAX Real Bottom of structure mm
Y.MIN Real Top of structure mm
Z.MIN Real Front microns
Z.MAX Real Back microns

**ELEC.NUMBER** specifies an electrode number that the thermal contact is coincident with.

# MORE DETAILS …

**Coordinate Definition Example**

A thermal contact is located where y-coordinate values range from 10 mm to the bottom side of the structure and x-coordinate values range from the left edge of the structure to the right edge of the structure (be default). The external temperature is set to 300K and a thermal resistance of 1 is added.

Thus, the temperature at y = 10 um will be greater than 300K once lattice heating effects occur.

**THERMCONTACT NUM=1 Y.MIN=10 EXT.TEMP=300 ALPHA=1**

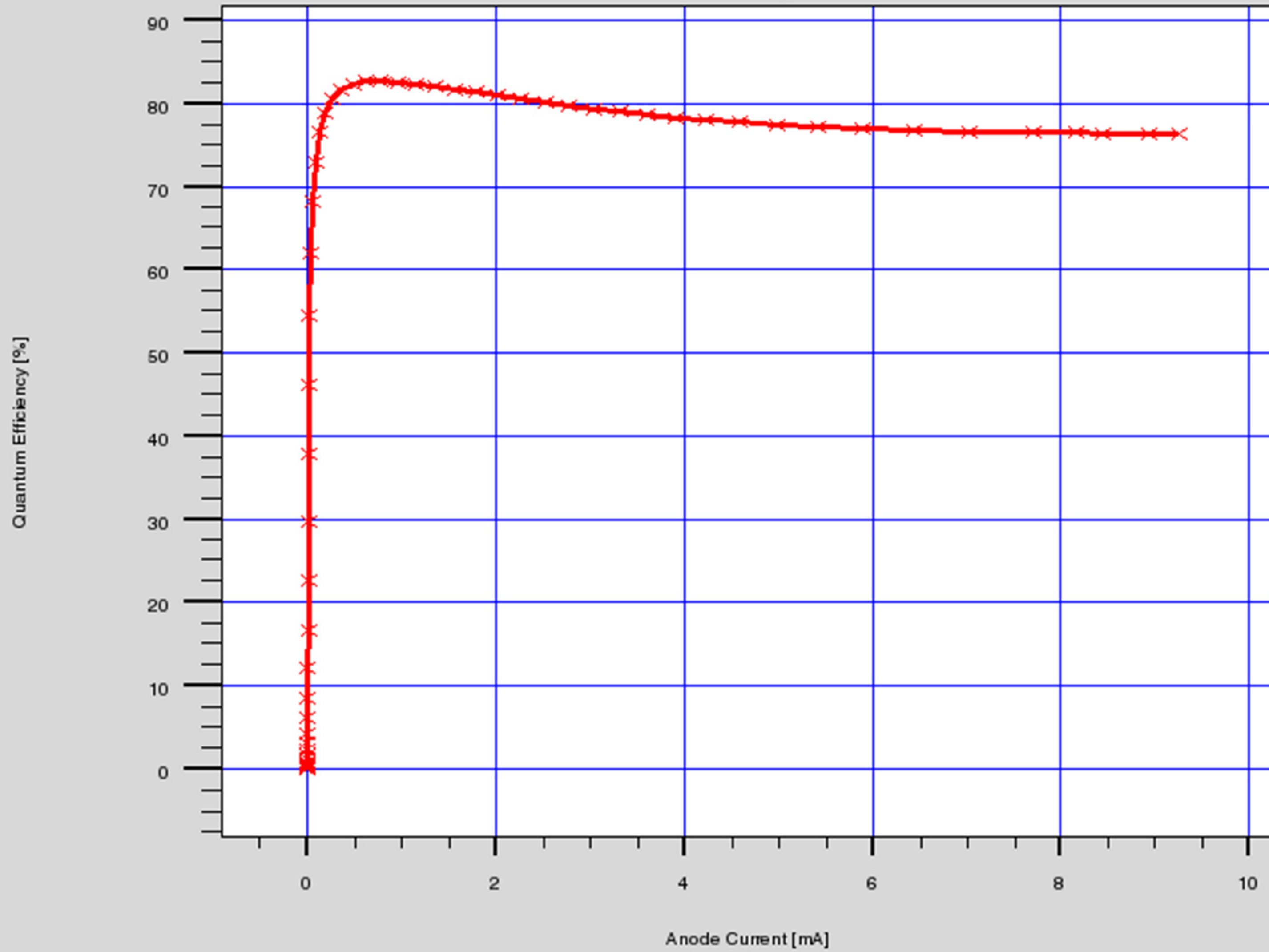
**Example Setting Thermal and Electrical Contacts Coincident**

The next statement line creates a thermal contact at the location of electrode #4. An external temperature of 400K is specified.

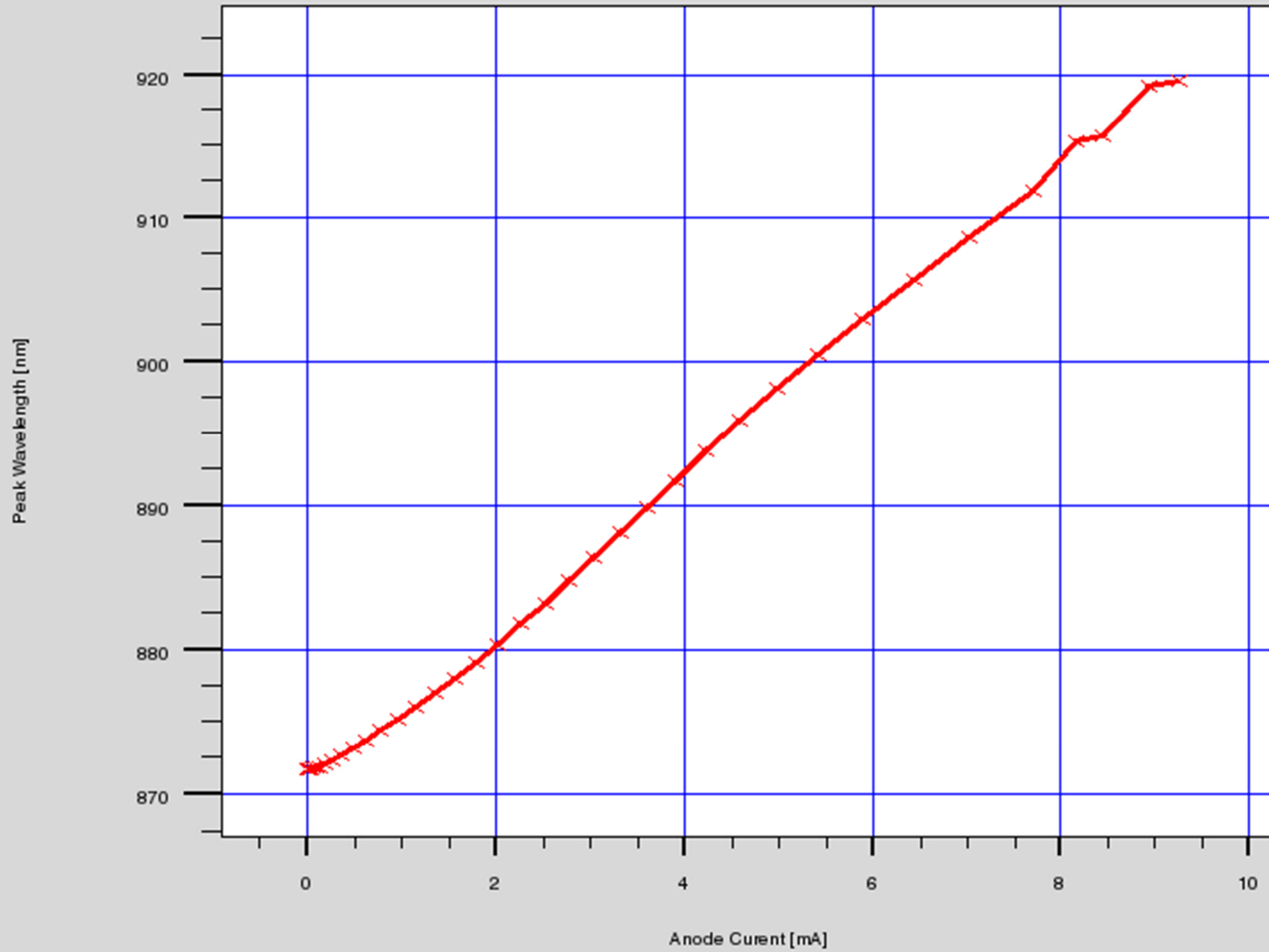
**THERMCONTACT NUM=2 ELEC.NUM=4 EXT.TEMP=400**

# EXAMPLE 3: SELF-HEATING EFFECTS IN LEDS

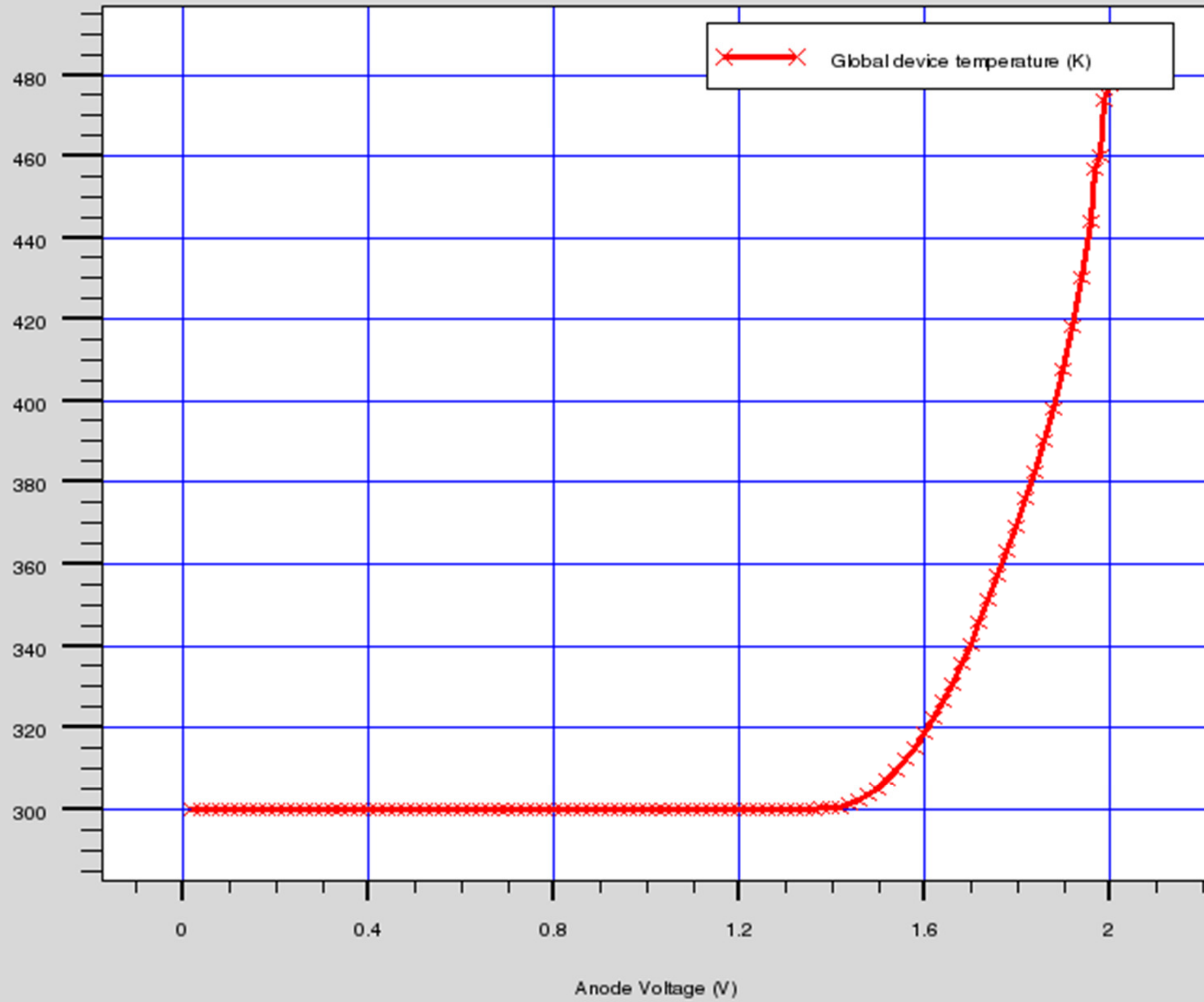
GAAS/ALGAAS BULK LED WITH SELF-HEATING EFFECT
CYLRINDRICAL STRUCTURE LED SIMUALTION
REQUIRE : DEVICE3D/GIGA3D



Internal Quantum Efficiency
Include the Self-Heating Effect
Quantum Efficiency [%]
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Anode Current [mA]



Red Shift due to the Self-Heating Effect
Anode Current vs Pleak Wavelength
920
910
900
890
880
870
Peak Wavelength [nm]
0
2
4
6
8
10
Anode Curent [mA]


Lattice Temperature depend on the Self-Heating Effect
Anode Voltage vs Lattice Temperature
Global device temperature (K)
480
460
440
420
400
380
360
340
320
300
0
0.4
0.8
1.2
1.6
2
Anode Voltage (V)