Advanced Optoelectronic project

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Introduction

p-contact
p-DBR
Oxide-confined layer
Passivation layer
Active QWs
n-DBR
GaAs substrate
n-contact
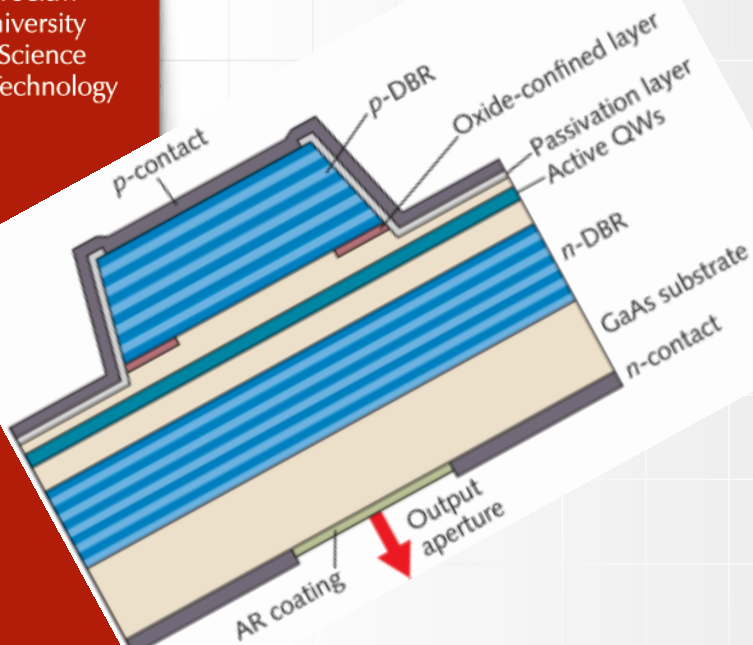Output aperture
AR coating

Wrocław University of Science and Technology

HR EXCELLENCE IN RESEARCH

CROSSLIGHT
Software Inc.

Simulation software by:

Crosslight Software Inc.

http://crosslight.com/

Dr inż. Damian Radziewicz

Wrocław 2018

Introduction

❖ Information about teacher

❖ Information about project

❖ Short information about APSYS

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Information about teacher

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Consultations:

Monday: 10^{00} a.m. – 12^{00} a.m., M-11

Information about project

Project	Terms
• APSYS	• I Report
• First easy structure simulation	**December 11th 2018**
• Second advanced structure simulation	• II Report
• Preparing Reports	**January 29th 2019**

APSYS informations 1

APSYS definition

APSYS is a general purpose 2D/3D modeling software program for semiconductor devices. Based on finite element analysis, it includes many advanced physical models such as hot carrier transport, heterojunction models and thermal analysis. APSYS offers a very flexible and simulation environment for modern semiconductor devices.

APSYS can be applied to the modeling and analysis of almost all devices except semiconductor lasers (which are simulated by other products **LASTIP** and **PICS3D**).

These include the following devices based on silicon and compound materials.

- 1. Silicon MOSFET, bipolar transistors and CCD.
- 2. HBT based on SiGe, AlGaAs and InGaAsP.
- 3. GaAs MESFET and Photodectors.
- 4. GaN HEMT.
- 5. Light Emitting Diodes (LED).
- 6. Electro-absorption modulators.
- 7. Organic semiconductor devices (OLED).
- 8. Compound, thin film and multi-junction Solar Cells.

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APSYS informations 2

APSYS can solve self-consistently the hydrodynamic equations, the heat transfer equations as well as the conventional drift-diffusion equations. Data generated by APSYS include the following:

- 1) Current versus voltage (I-V) characteristics.
- 2) 2D potential, electric field and current distributions.
- 3) 2D distributions of electron and hole concentrations.
- 4) 2D distributions of hot carrier temperatures in the hydrodynamic model.
- 5) 2D distributions of lattice temperature for the heat transfer model.
- 6) Band diagrams under various bias conditions.
- 7) Results of AC small signal analysis for any frequency range. Extraction of 2-port AC parameters such S- and Y- parameters.
- 8) Quantum well subband structure with valence mixing model for quantum devices.
- 9) 2D distributions of occupancy and concentration of deep level traps in a semiconductor.
- 10) 2D optical field distribution for photonic devices such as photodetectors.
- 11) Spontaneous emission spectrum as a function of current for LED's.
- 12) All of the above as a function of time (transient model).
- 13) All of the above at different environment temperatures.

APSYS informations 3

- **.geo** - The main input file that describe the full details of the device geometry and the initial mesh allocation.
- **.sol** - The main input file that defines the material properties and controls the bias and other conditions of main equation solver.
- **.layer** - An important auxiliary input file that uses the layer structure description to generate the .geo, .doping, .mater and .mplt files,
- **.doping** which contains doping information that is to be included in the .sol file.
- **.mater** which contains material information that is to be included in the .sol file.
- **.mplt** can be used to plot the mesh generated from .geo file.
- **.gain** file is another important auxiliary input file that can be used to preview the optical gain spectrum, spontaneous emission rate spectrum, quantum well subbands, and other critical physical properties. This may be used by the user to do some preliminary estimate before the full simulation is performed.
- **.out** files may appear as .out 01, .out 02, etc.. These are numerical output data from the main equation solver. They can be used by the .plt program to be plotted. These output files are not meant to be understood by the user.
- **.std** files may appear as .std 01, .std 02, etc.. These are another form of numerical output data from the main equation solver. They can be used by the CrosslightView program to be displayed in 3D color graphics. These output files can be understood by the user should there were such a need.
- **.plt** file is used to plot the data in .out output files. APSYS calls the public domain software GNUPLOT to display the graphics in various computer platforms and printers.

APSYS informations 4

**Basic procedure:**

1. Run the "*.layer" files to 'process and generate the .geo files.

2. Run the "*.geo" files to generate the mesh.

3. Run the main equation solver with the "*.sol" input file .

4. (Optional) Results can also be plotted by using CrosslightView. This can launched by right-clicking on the .std files in SimuCenter or with the main menu: "Action → View Results → CrosslightView". The program can also be launched independently from the Start Menu.

APSYS informations 5
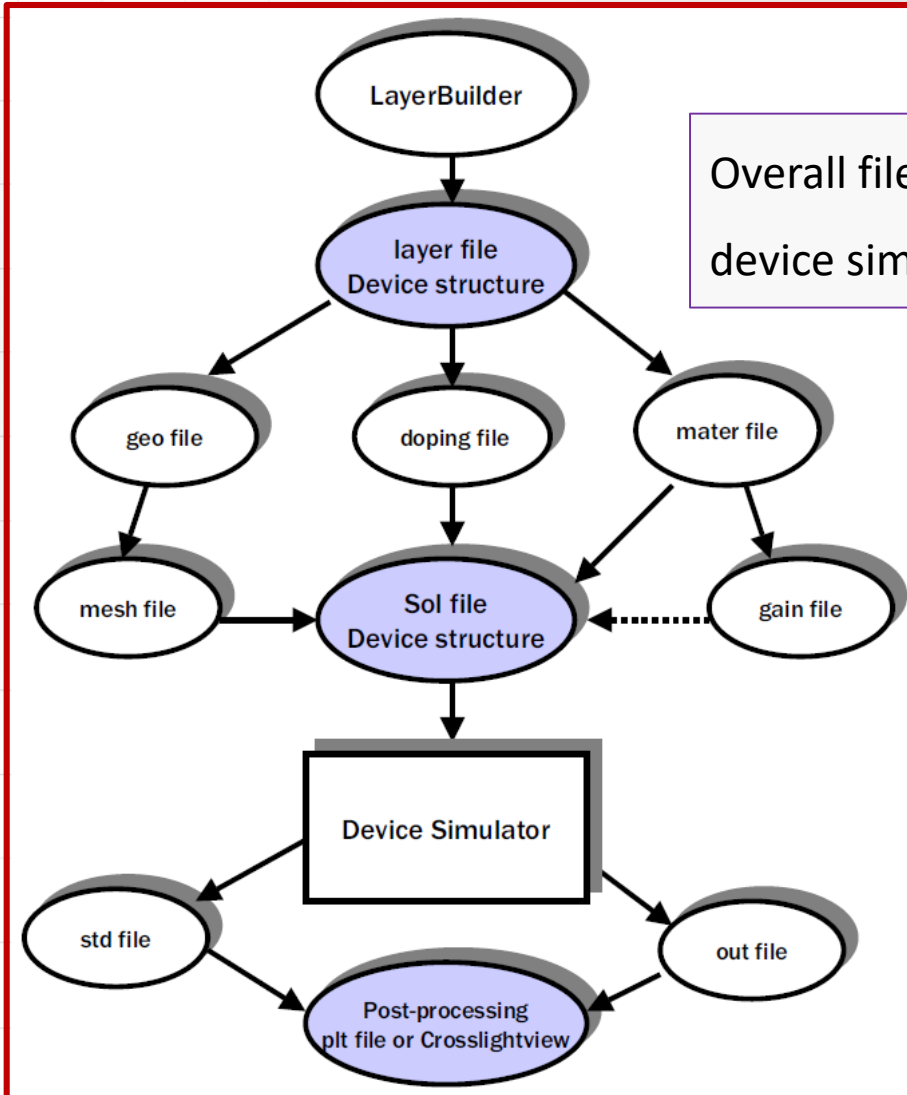
Overall file structure and flow chart of Crosslight device simulators

Only shaded files need to be set up by user.

APSYS informations 6

Defining the device structure – cross section

1 μm - Al$_{0.5}$Ga$_{0.5}$As - p=1.0×10^{24} m^{-3}
0.2 μm - GaAs - undoped; active region
1 μm - Al$_{0.5}$Ga$_{0.5}$As - n=1.0×10^{24} m^{-3}

APSYS informations 6

Defining the device structure – test1.layer file

```
$file:test1.layer
begin_layer
column column_num=1 w= 0.150000E+01 mesh_num=2 r=1.
bottom_contact column_num=1 from=0 to= 0.150000E+01 &&
 contact_num=1 contact_type=ohmic
$
layer_mater macro_name=algaas &&
 var_symbol1=x var1= 0.500000E+00 &&
 column_num=1
layer d= 0.100000E+01 n= 13 &&
 n_doping1= 0.100000E+25 &&
 r= 0.800000E+00
$
layer_mater macro_name=algaas &&
 var_symbol1=x var1= 0.000000E+00 &&
 active_macro=AlGaAs &&
 avar_symbol1=xw avar1= 0.000000E+00 &&
 column_num=1
layer d= 0.200000E+00 n= 5 &&
 shift_center= -0.111111E-01 &&
 r= -0.120000E+01
$
layer_mater macro_name=algaas &&
 var_symbol1=x var1= 0.500000E+00 &&
 column_num=1
layer d= 0.100000E+01 n= 11 &&
 p_doping1= 0.100000E+25 &&
 r= 0.120000E+01
$
top_contact column_num=1 from=0 to= 0.150000E+01 &&
 contact_num=2 contact_type=ohmic
end_layer
```
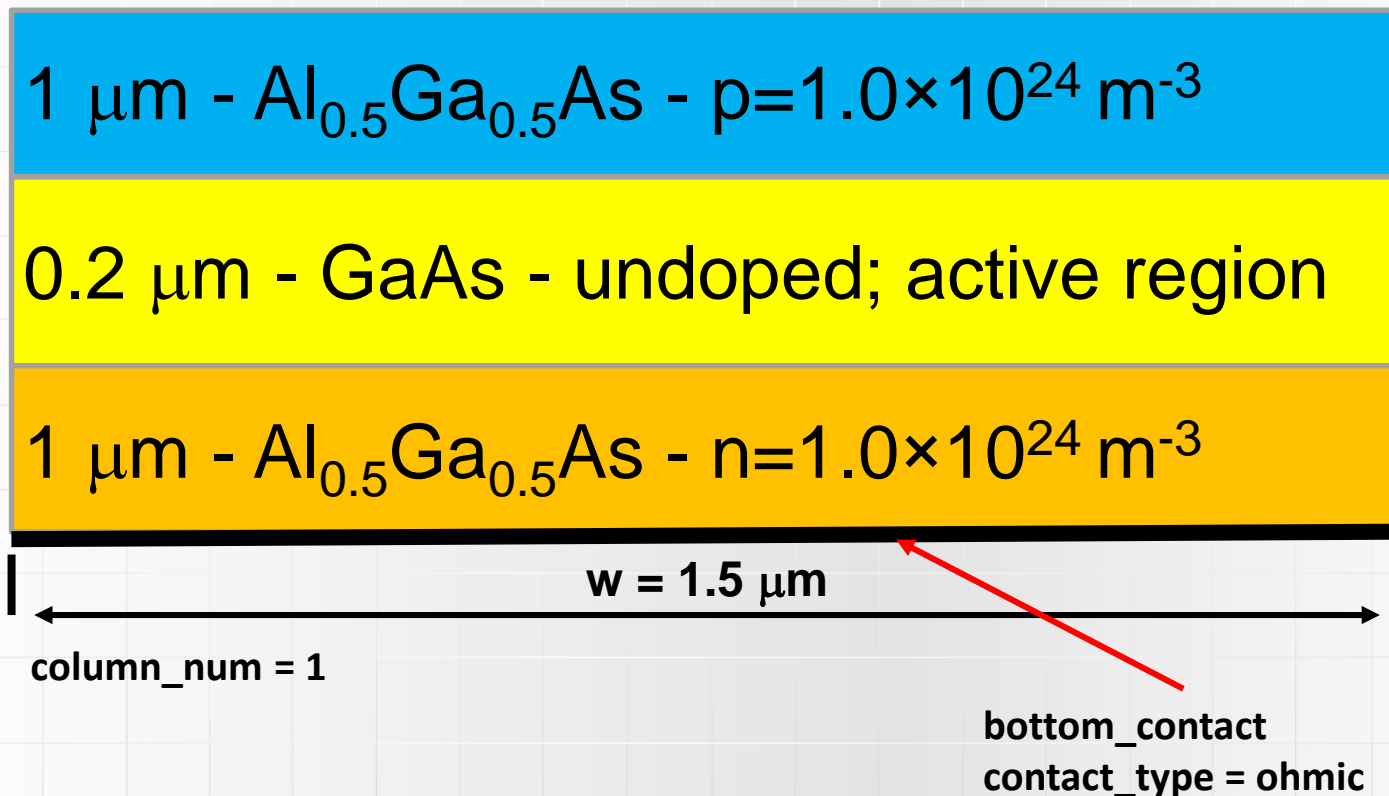
APSYS informations 6

Defining the device structure – test1.layer file

$file:test1.layer
begin_layer
column column_num=1 w= 0.150000E+01 mesh_num=2 r=1.
bottom_contact column_num=1 from=0 to= 0.150000E+01 &&
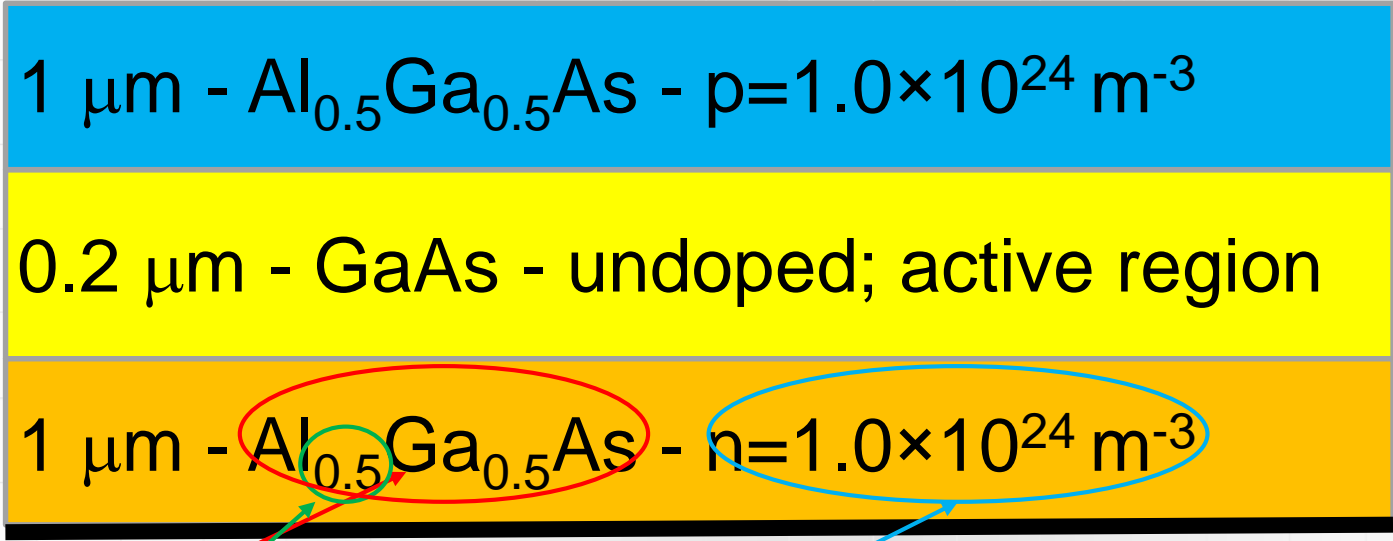 contact_num=1 contact_type=ohmic

$$1\ \mu m - Al_{0.5}Ga_{0.5}As - p=1.0\times10^{24}\ m^{-3}$$

$$0.2\ \mu m - GaAs - undoped;\ active\ region$$

$$1\ \mu m - Al_{0.5}Ga_{0.5}As - n=1.0\times10^{24}\ m^{-3}$$

$w = 1.5\ \mu m$

column_num = 1

bottom_contact
contact_type = ohmic

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Defining the device structure – test1.layer file

layer_mater macro_name=algaas &&
 var_symbol1=x var1= 0.500000E+00 &&
 column_num=1
layer d= 0.100000E+01 n= 13 &&
 n_doping1= 0.100000E+25 &&
 r= 0.800000E+00

$1\ \mu m - Al_{0.5}Ga_{0.5}As - p=1.0\times10^{24}\ m^{-3}$

$0.2\ \mu m - GaAs - undoped;\ active\ region$

$1\ \mu m - Al_{0.5}Ga_{0.5}As - n=1.0\times10^{24}\ m^{-3}$

d

macro_name=algaas &&

var_symbol1=x var1=0.5

$n\_doping=1.0\times10^{24}\ m^{-3}$

layer d=1 μm

APSYS informations 6

Defining the device structure – test1.layer file

layer_mater macro_name=algaas &&
 var_symbol1=x var1= 0.000000E+00 &&
 active_macro=AlGaAs &&
 avar_symbol1=xw avar1= 0.000000E+00 &&
 column_num=1
layer d= 0.200000E+00 n= 5 &&
 shift_center= -0.111111E-01 &&
 r= -0.120000E+01

1 μm - Al$_{0.5}$Ga$_{0.5}$As - p=1.0×10^{24} m^{-3}

0.2 μm - GaAs - undoped; active region

1 μm - Al$_{0.5}$Ga$_{0.5}$As - n=1.0×10^{24} m^{-3}

d
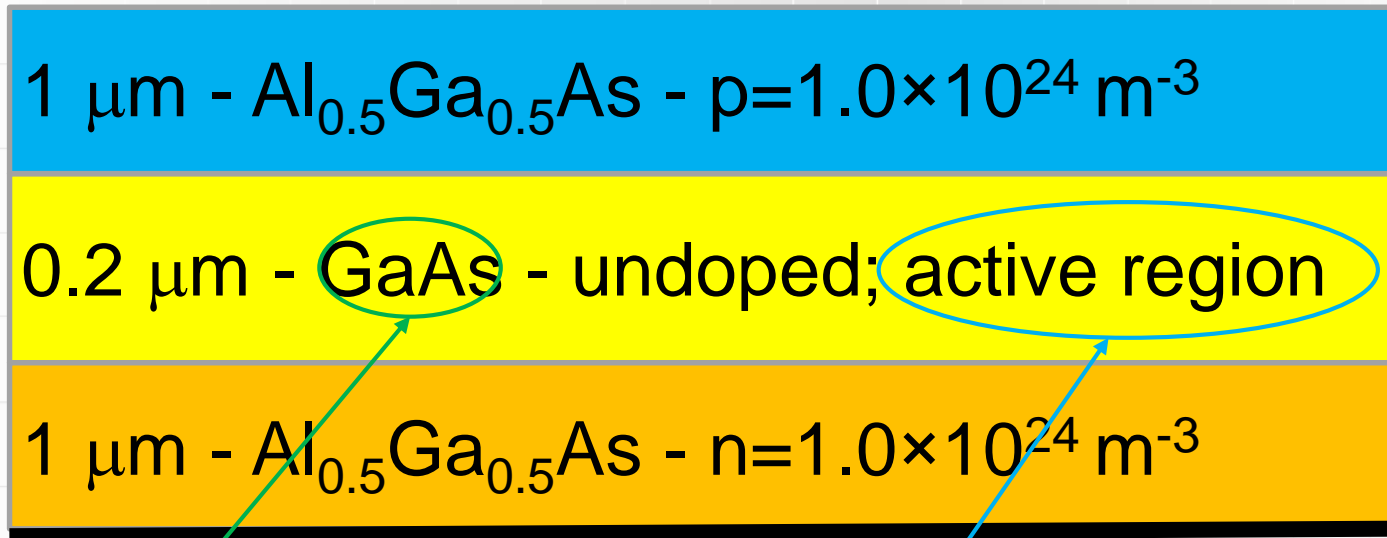
macro_name=algaas &&

var_symbol1=x var1=0

active_macro=AlGaAs
avar_symbol1=xw avar1=0

layer d=0.2 μm

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APSYS informations 6

Defining the device structure – test1.layer file

top_contact column_num=1 from=0 to= 0.150000E+01 &&
contact_num=2 contact_type=ohmic

top_contact
contact_type = ohmic

$1 \ \mu m - Al_{0.5}Ga_{0.5}As - p=1.0\times10^{24} \ m^{-3}$

$0.2 \ \mu m - GaAs$ - undoped; active region

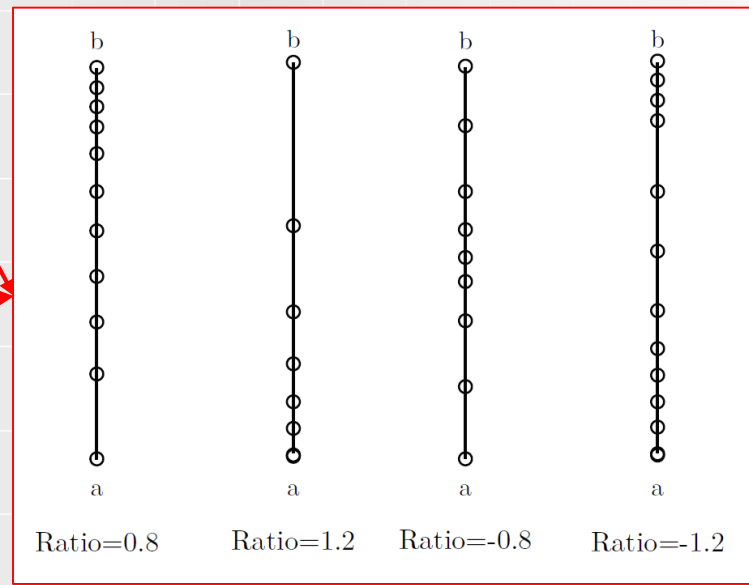$1 \ \mu m - Al_{0.5}Ga_{0.5}As - n=1.0\times10^{24} \ m^{-3}$

APSYS informations 6

Defining the device structure – test1.layer file

```
$file:test1.layer
begin_layer
column column_num=1 w= 0.150000E+01 mesh_num=2 r=1
bottom_contact column_num=1 from=0 to= 0.150000E+01 &&
  contact_num=1 contact_type=ohmic
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layer_mater macro_name=algaas &&
  var_symbol1=x var1= 0.500000E+00 &&
  column_num=1
layer d= 0.100000E+01 n= 13 &&
  n_doping1= 0.100000E+25 &&
  r= 0.800000E+00
$
layer_mater macro_name=algaas &&
  var_symbol1=x var1= 0.000000E+00 &&
  active_macro=AlGaAs &&
  avar_symbol1=xw avar1= 0.000000E+00 &&
  column_num=1
layer d= 0.200000E+00 n= 5 &&
  shift_center= -0.111111E-01 &&
  r= -0.120000E+01
$
layer_mater macro_name=algaas &&
  var_symbol1=x var1= 0.500000E+00 &&
  column_num=1
layer d= 0.100000E+01 n= 11 &&
  p_doping1= 0.100000E+25 &&
  r= 0.120000E+01
$
top_contact column_num=1 from=0 to= 0.150000E+01 &&
  contact_num=2 contact_type=ohmic
end_layer
```


Effects of different ratio on putting mesh points on an edge (a b).

The number of vertical mesh lines for the column.

The number of mesh lines to be placed in the layer.

End of Introduction