3D Simulation of SiC MESFET

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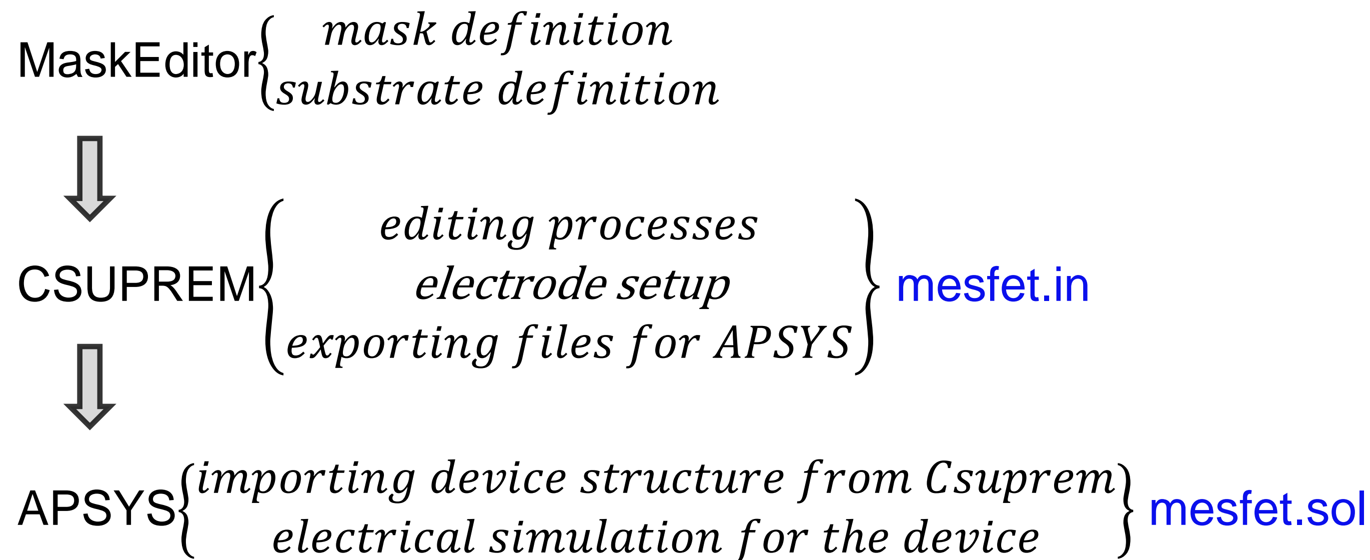
Introduction to Simulation Flow

3D simulation of a channel-recessed SiC MESFET is carried out by *MaskEditor, CSUPREM and APSYS*.

File structure in this simulation:



Reference structure: *C.L.Zhu et al. Solid-State Electronics 51 (2007) 343-346*

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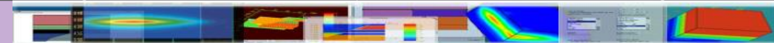
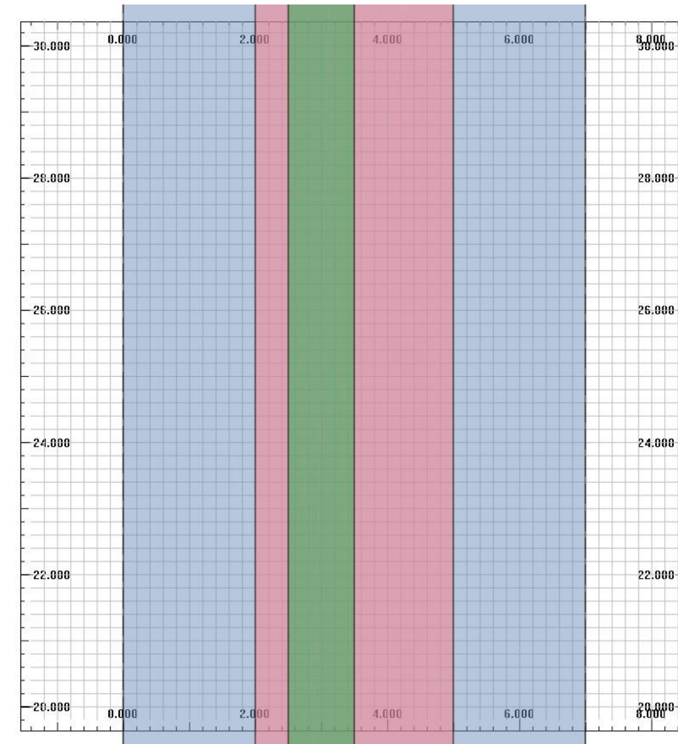


3D Process Simulation by MaskEditor

MESFET mask patterns defined in MaskEditor:

- Gray mask is the scope of substrate
- Pink mask is used to remove cap layer
- Green mask is used to generate metal-gate

No.	Label	Color	Purpose	Polarity	Bend
☑ 1	semi_sub		general	n	☐
☑ 2	sic_etch		general	n	☐
☑ 3	Nickel_etch		general	p	☐



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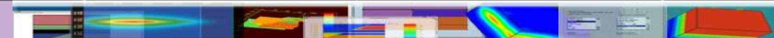

3D Process Simulation by CSUPREM

Simplified processes Step 1: S.I.SiC Substrate

Run mesfet.in:
init
struct outf=01_semi_inlu_sub.str

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3D Process Simulation by CSUPREM

Step 2: 4H-SiC epitaxy

```
include file=mesfet1.msk
deposit 4h_sic p-buffer
deposit 4h_sic ni.impurity
struct outf=02_epitaxy.str
```

Material Number
4h_sic
s.i.sic

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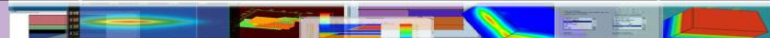
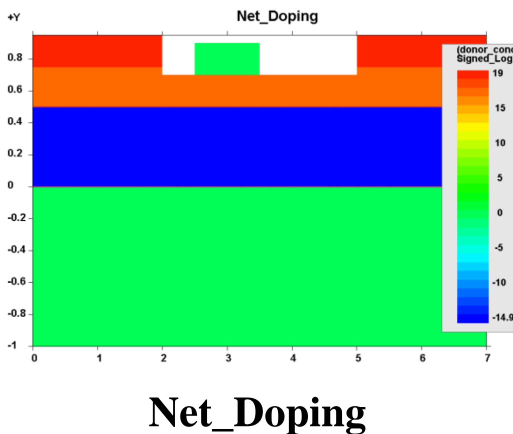


3D Process Simulation by CSUPREM

Step 3: dry etch 4H-SiC

include file=mesfet2.msk
etch dry 4h_sic thick=0.25
struct outf=03_etch_recesse.str



Net_Doping

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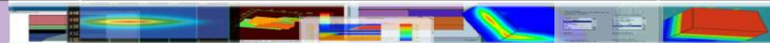

3D Process Simulation by CSUPREM

Step4: deposit nickel

deposit nickel thick=0.2
struct outf=04_deposit_Ni.str

Material Number
nickel
4h_sic
s.i.sic

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3D Process Simulation by CSUPREM

Step 5: lift-off nickel outside the gate area

```
include file=mesfet3.msk
etch dry nickel thick=1.
struct outf=05_etch_gate.str
```


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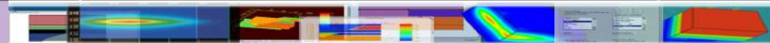
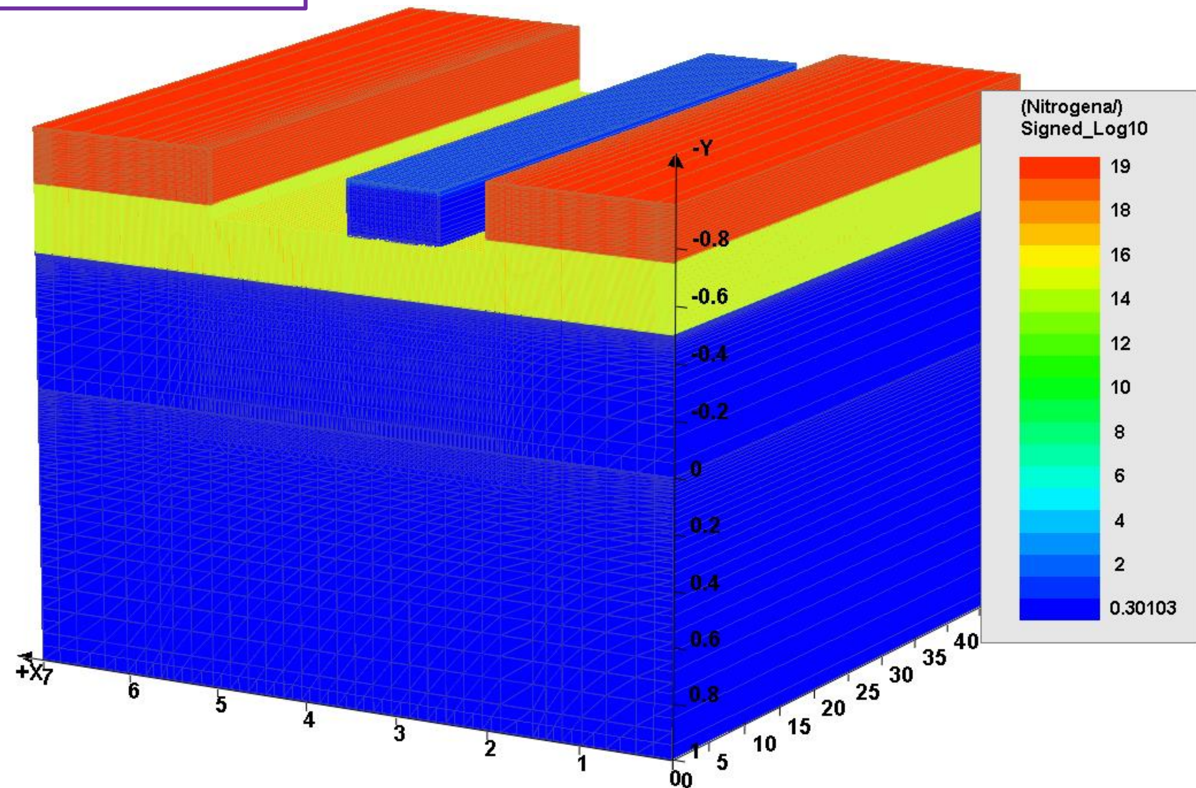


3D Process Simulation by CSUPREM

Step 6: Final 3D structure: channel-recessed structure

activation.mode al.impurity fraction=1.0
activation.mode ni.impurity fraction=1.0
struct outf=06_final.str [1]



[1] C.L.Zhu et al. Dual-channel 4H-SiC metal semiconductor field effect transistors. Solid-State Electronics 51 (2007) 343-346.

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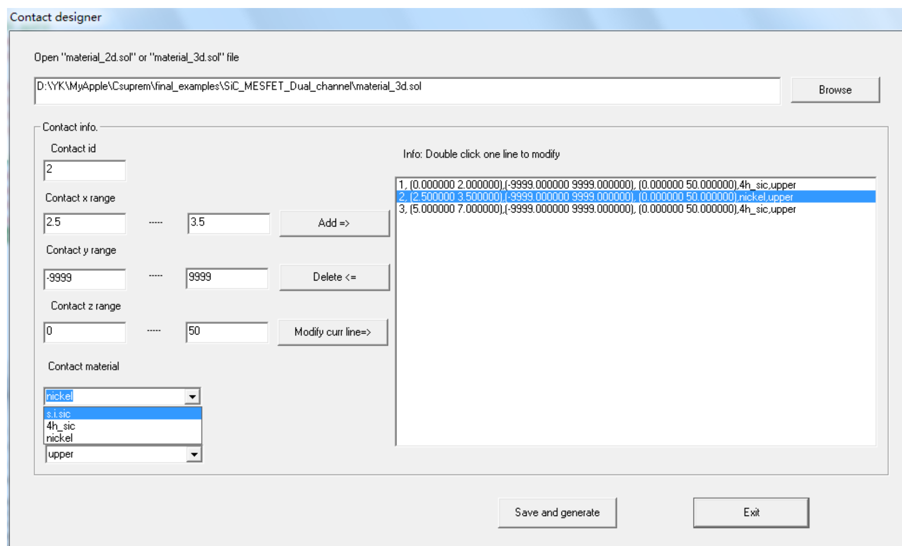
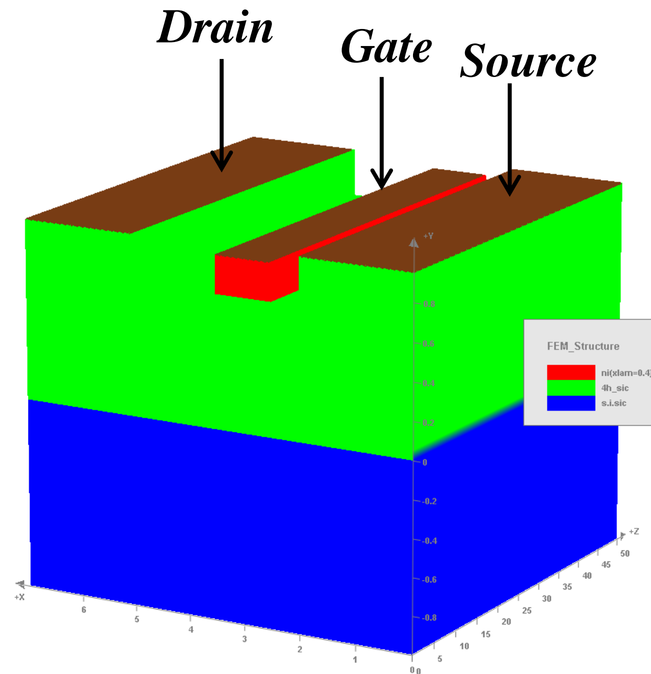
3D Device Simulation by APSYS

Set electrode position:

Electrode information is contained in contact_3d.sol





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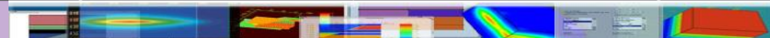

3D Device Simulation by APSYS

- Doping dependent mobility model

$$\mu_{0i} = \mu_{1i} + \frac{(\mu_{2i} - \mu_{1i})}{1 + (\frac{N_D + N_A + \sum_j N_{\mathrm{tj}}}{N_{ri}})^{\alpha_i}} \quad (\mathrm{i} = n\ or\ p)$$

- The Canali model for field dependent mobility

$$\mu_i = \frac{\mu_{oi}}{\left(1 + \left(\frac{\mu_{oi} F}{v_{si}}\right)^{\beta_i}\right)^{\frac{1}{\beta_i}}} \quad (\mathrm{i} = n\ or\ p)$$

- Chynoweth model has been used to calculate impact ionization

$$\alpha = \alpha^{\infty} e^{-(F_{ci}/F)^{k_i}} \quad (\mathrm{i} = n\ or\ p)$$

- Incomplete ionization of impurities in SiC is important

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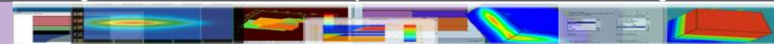

3D Device Simulation by APSYS

- Describe impact ionization parameters in mesfet.sol:

```
impact_chynoweth  mater = 2   &&
   hole_setnum = 1 hole_set1 =  [3.41e+10,2.50e+09,1.]  &&
   elec_setnum = 1 elec_set1 =  [9.76e+11,3.30e+09,1.]
```

- Describe interface states between Ni/4H-SiC in mesfet.sol:

```
doping impurity=fix_charge  charge_type=negative
```

- Describe traps in 4H-SiC in mesfet.sol:

```
doping impurity=trap_1  charge_type=acceptor
trap_level_1  value=0.400 mater=2
trap_ncap_1  value=3.e-7 mater=2
trap_pcap_1  value=3.e-8 mater=2
```


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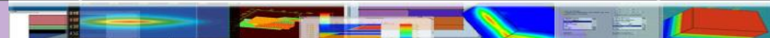

Simulation Results

3D potential distribution

Gate voltage= -2V
Drain voltage=40V

Differential Potential

40
35
30
25
20
15
10
5
0
-2

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Simulation Results

2D current distribution

Gate voltage=-2V
Drain voltage=40V

Total Curr. Mag (A/cm^2)

+Y

0.9
0.8
0.7
0.6
0.5
0.4

1.5 2 2.5 3 3.5 4 4.5 5 5.5 +X

buffer

Total Curr. Mag (A/cm^2)
120000
100000
80000
60000
40000
20000
0

Elec_Conc (E18/cm^3)

Elec_Conc (E18/cm^3)
0.3
0.25
0.2
0.15
0.1
0.05
0

Depletion Regions

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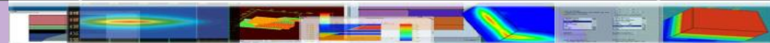
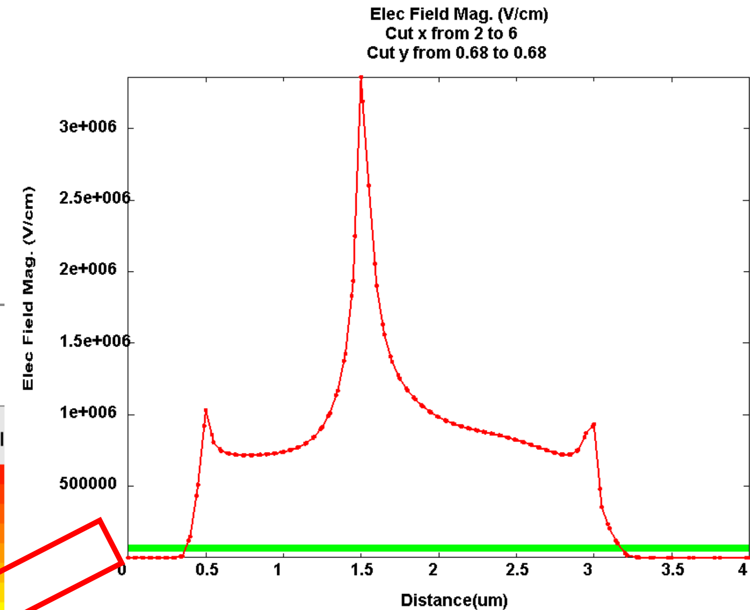


Simulation Results

2D electric field distribution

Vg=-6V Vd=160V



Elec Field Mag. (V/cm)

+Y

0.9

0.8

0.7

0.6

0.5

0.4

0.3

2 3 4 5 6 +X

Max Elec Field (x=3.5 , y=0.7001 , 1.47425e+007)

Elec Fiel

1.2e+006

1e+006

800000

600000

400000

200000

0

1D cut electric field distribution in the channel region. It shows that the high, sharp peak at the drain side gate edge.

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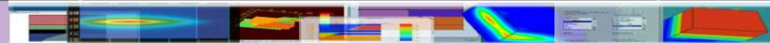


Simulation Results

Impact Ionization

Vg=-6V Vd=160V

Gate field emission induced breakdown of the device

Log10 (impact_ionization (1/cm^3/s))

+Y

0.9
0.8
0.7
0.6
0.5
0.4

1 2 3 4 5 6 +X

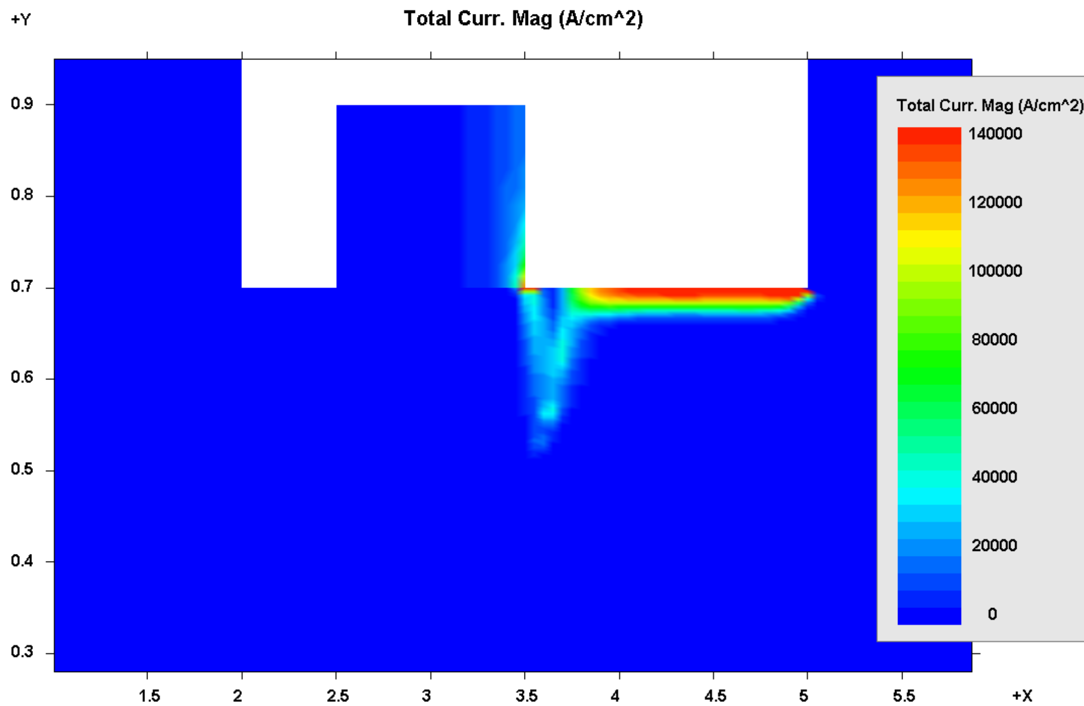
Log10 (impact_ionization (1/cm^3/s))

30
25
20
15
10
5
0
-5
-10
-15
-20

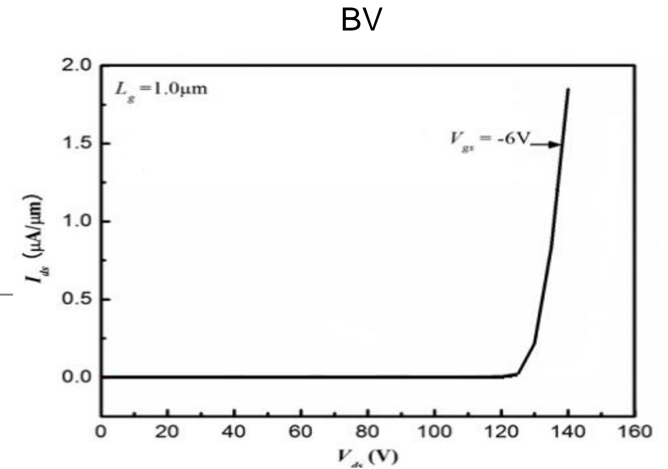
Simulation Results

Gate Current after the breakdown

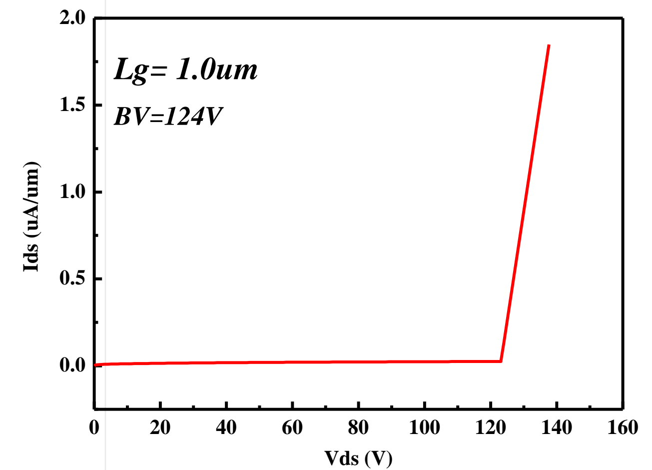
Vg=-6V   Vd=160V



BV



Experimental Result



Simulation Result

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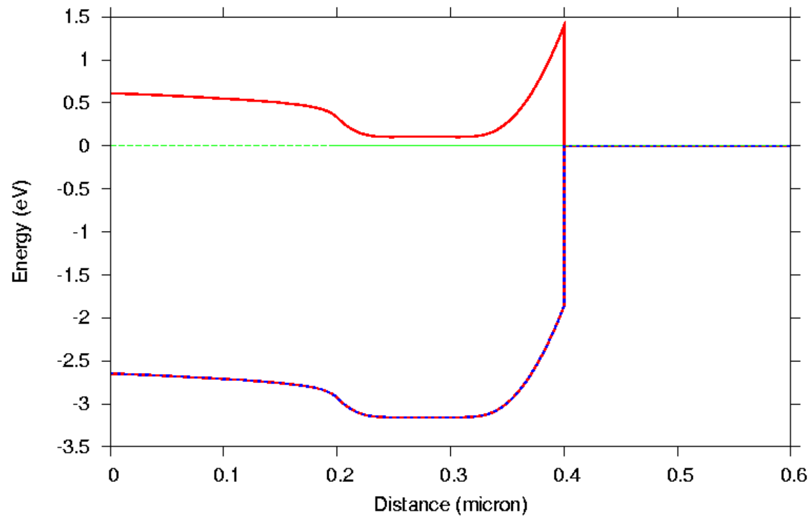
Simulation Results

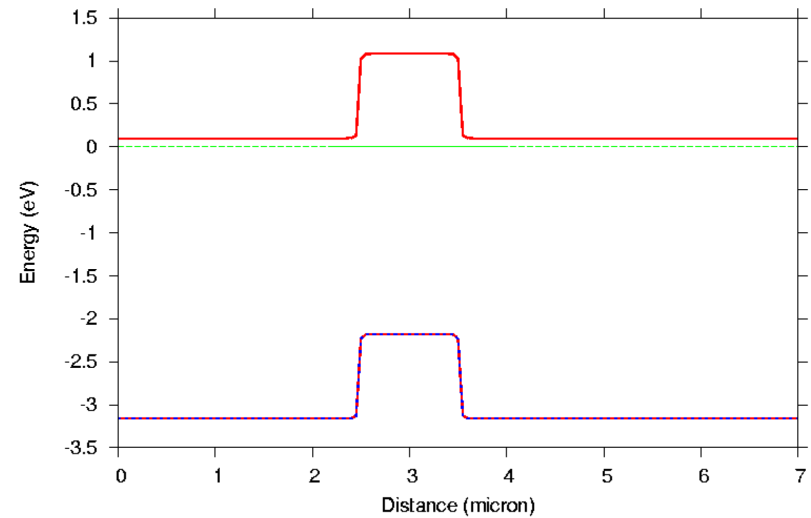
1D band diagram

Vg=0V Vd=0V

y-direction(x=0.3)



x-direction(y=0.69)



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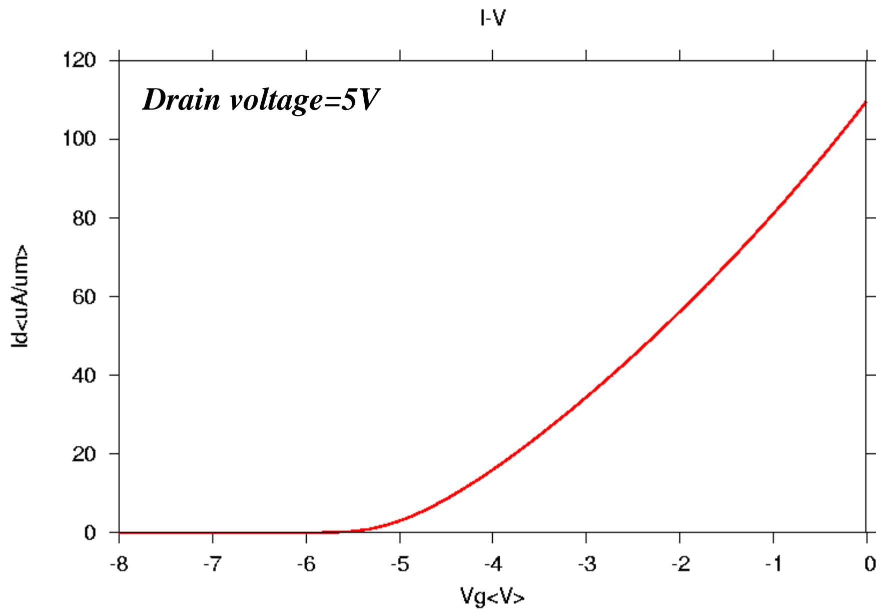
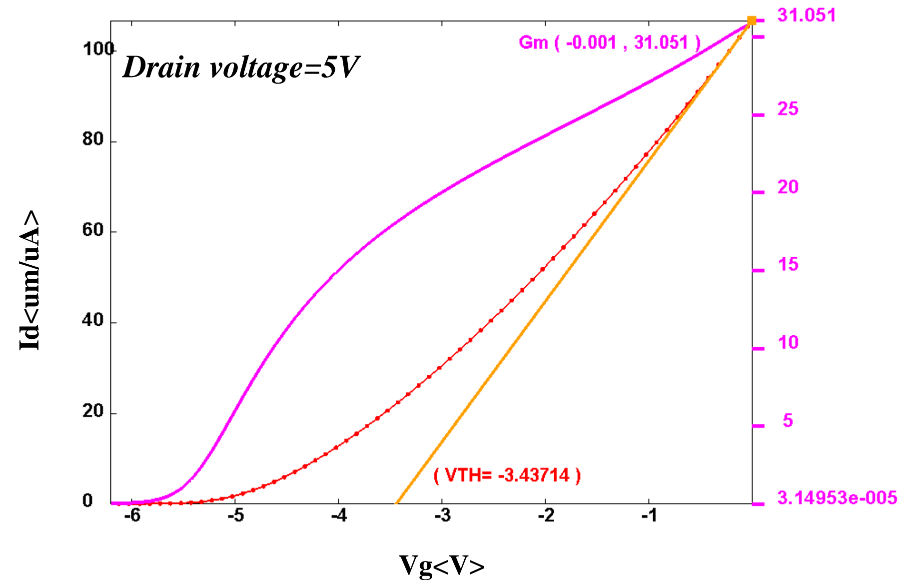
Simulation Results

Threshold voltage and g_m





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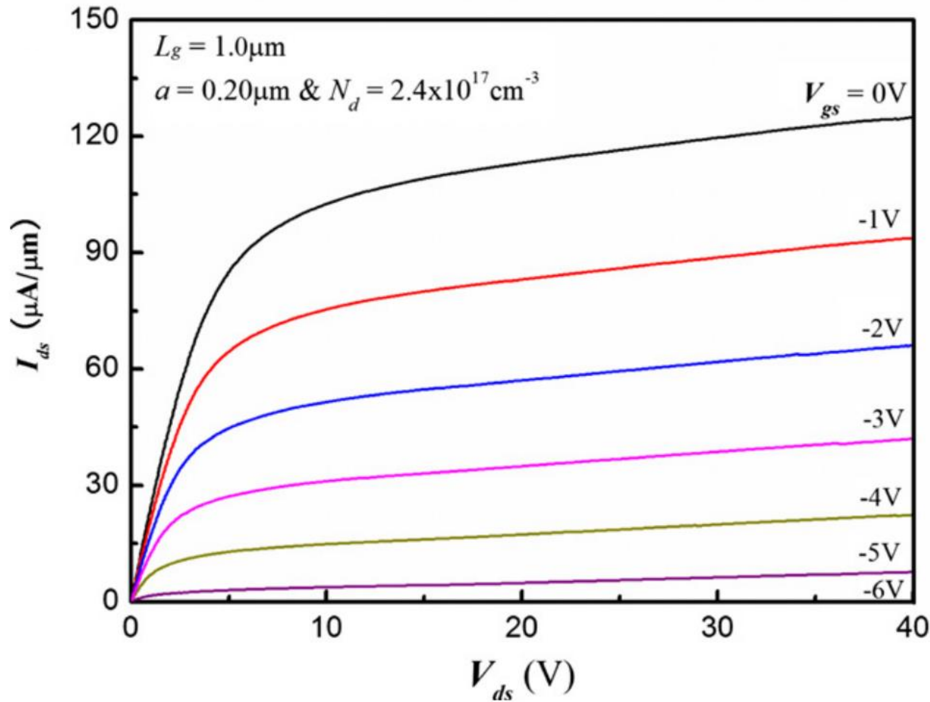
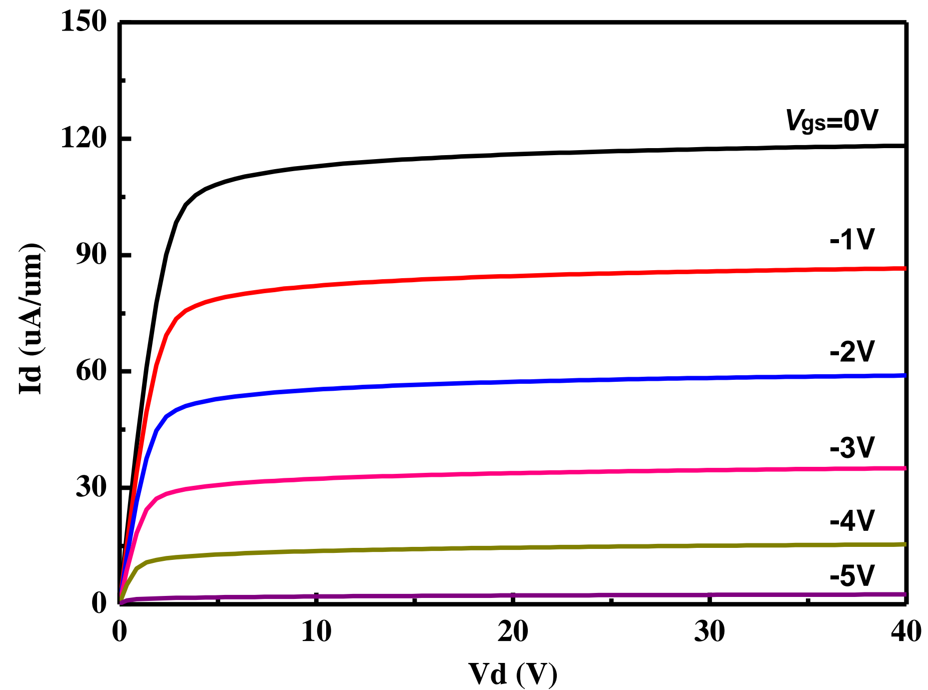
Simulation Results

I_d-V_d family of curves



Experimental Result



Simulation Result

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