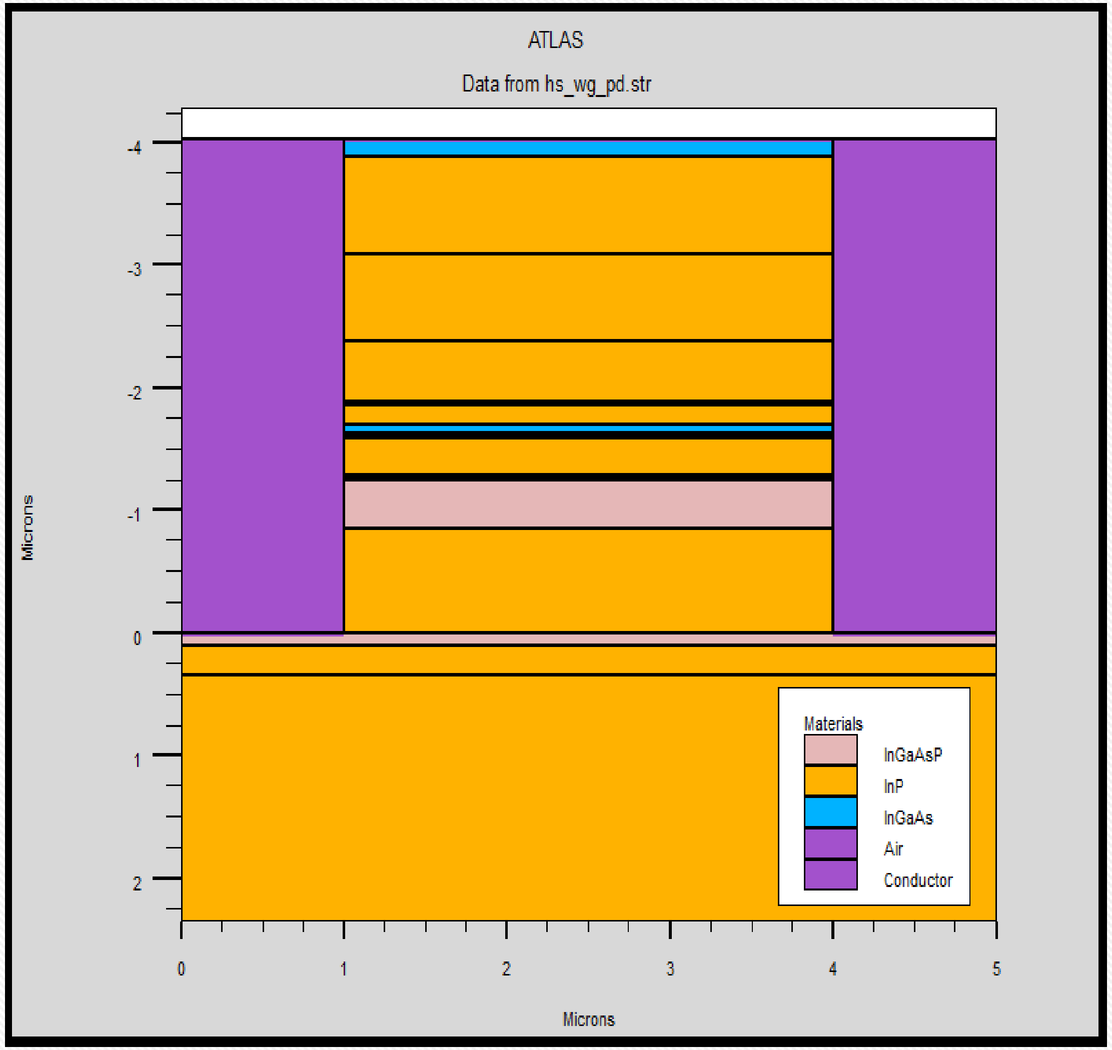
Project 1 - High Speed Waveguide UTC Photodetector, I-V Curve

Michael Benker

ECE530 – Advanced Electronics/Optoelectronics
University of Massachusetts Dartmouth



Design Specifications:

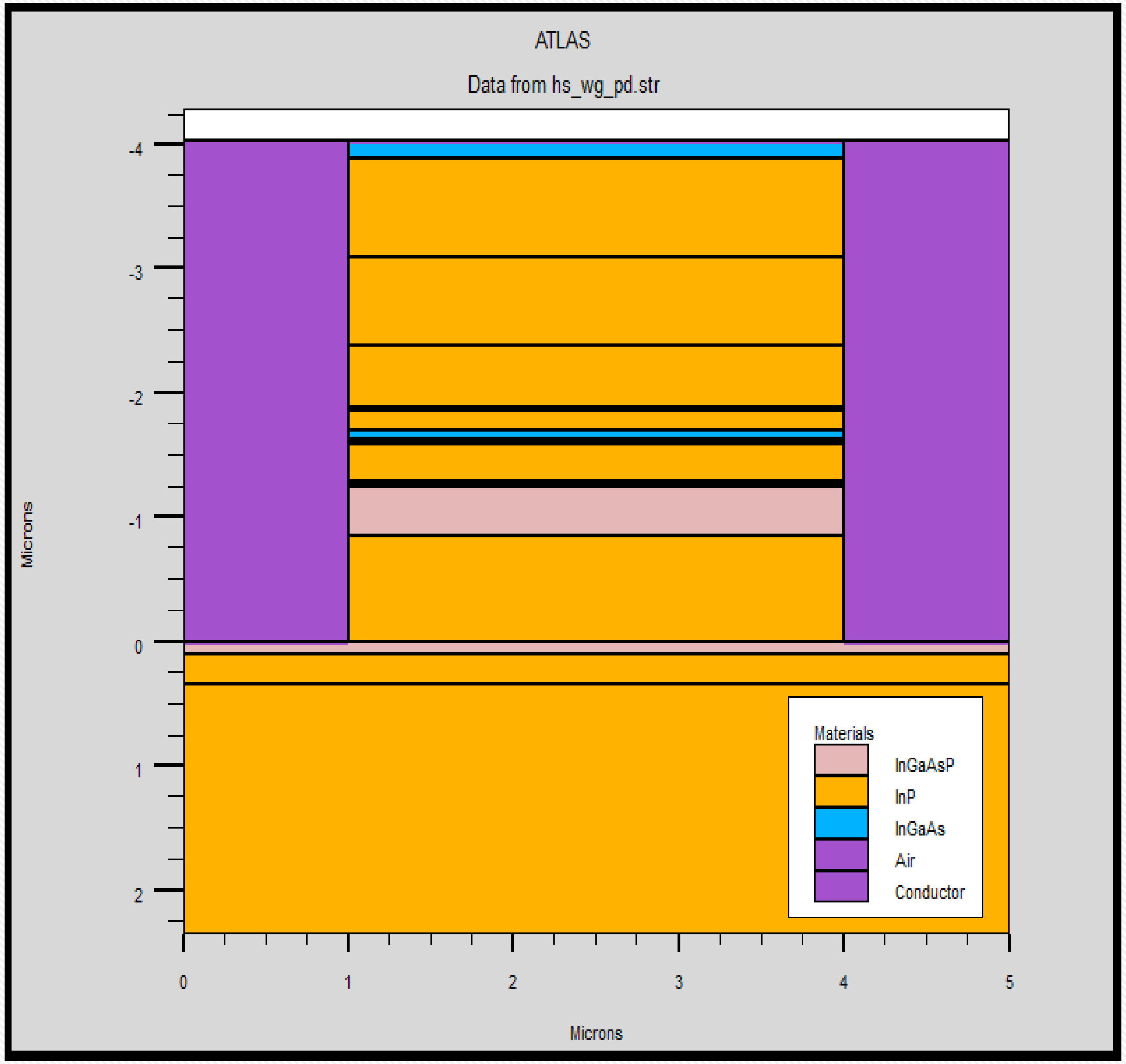
Construct an Atlas model for a waveguide UTC photodetector. The P contact is on top of layer R5, and N contact is on layer 16.

The PIN diode's ridge width is 3 microns.

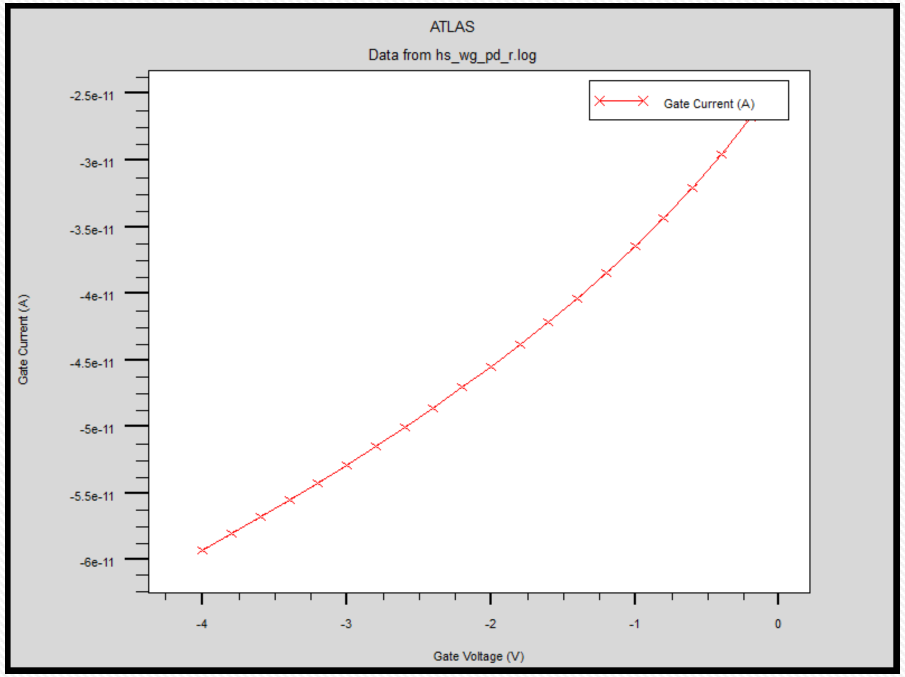
Please find:

The IV curve of the photodetector (both reverse biased and forward bias)

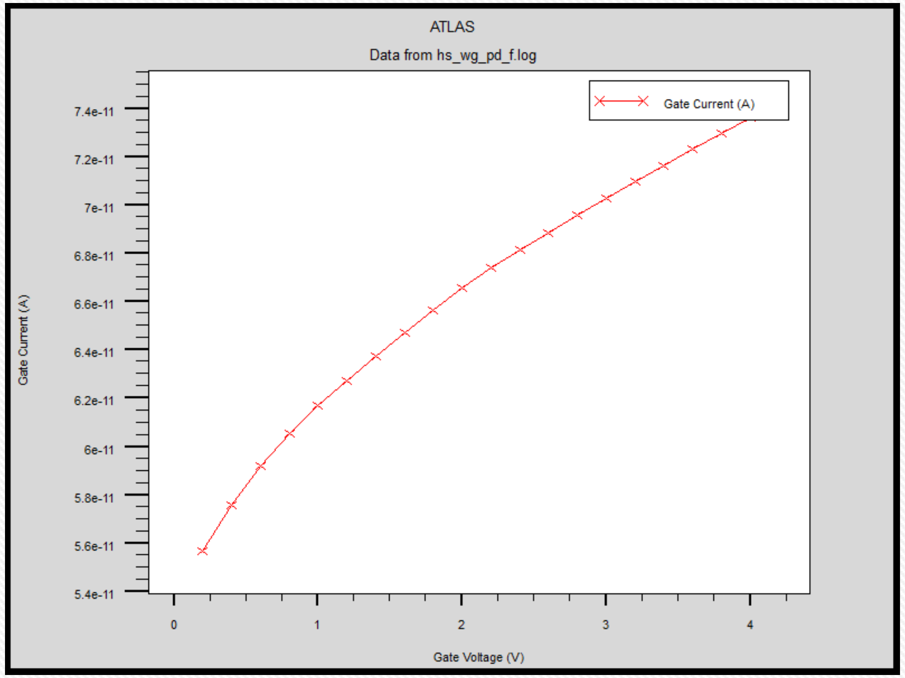
Simulation Results



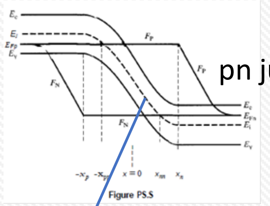
Negative Bias



Positive Bias

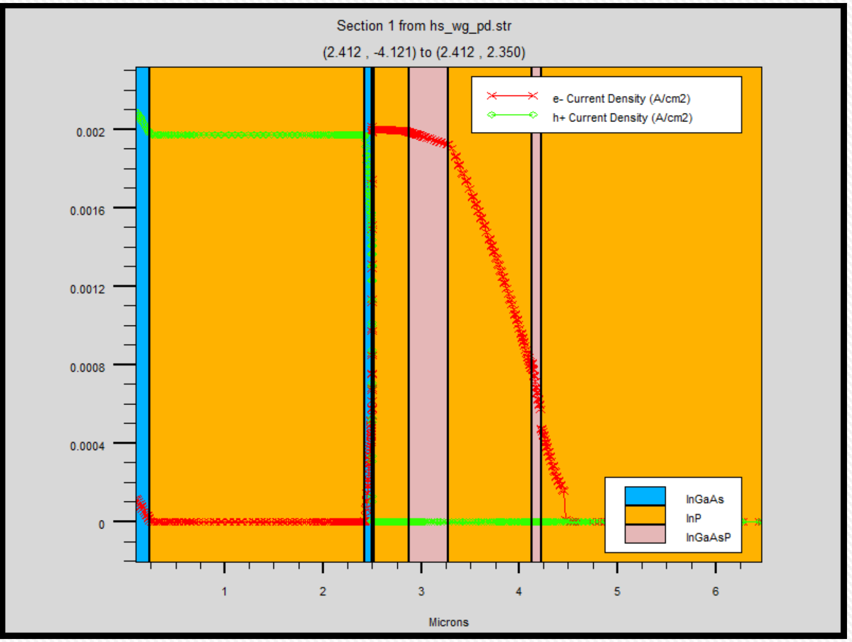


Other Results – Middle Cross Section

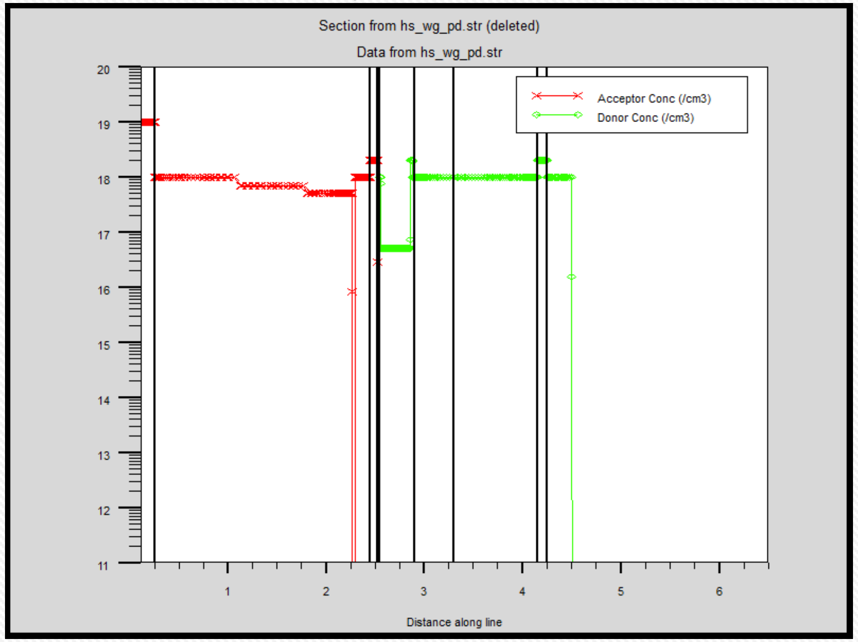


pn junction

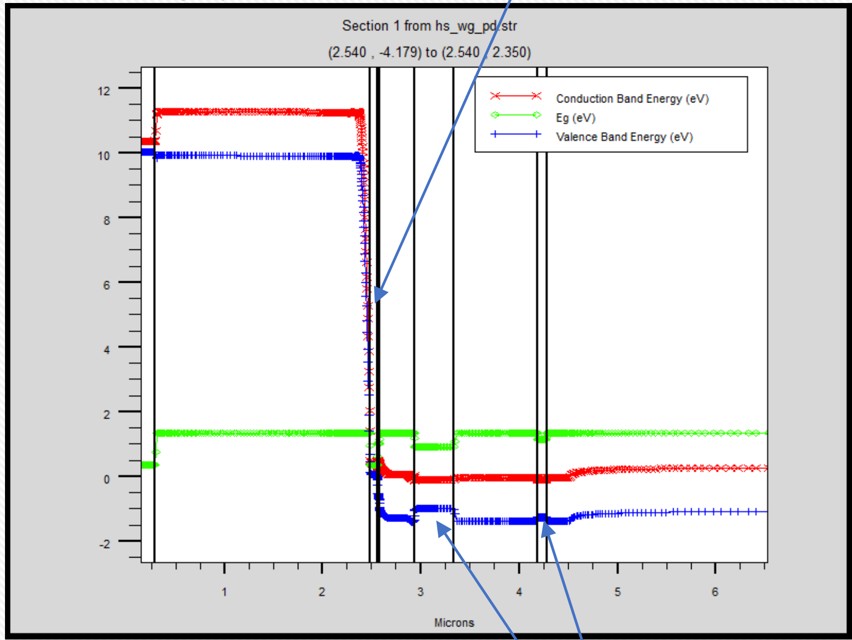
Electron & Hole Current Densities



Donor & Acceptor Concentrations



Bandgap & Conduction, Valence Bands



Current Density in a p-n junction (page 33):

$$J = q\left[\frac{D_n n_{p0}}{L_n} + \frac{D_p p_{n0}}{L_p}\right]\left[\exp\left(\frac{qV_A}{kT}\right) - 1\right]$$

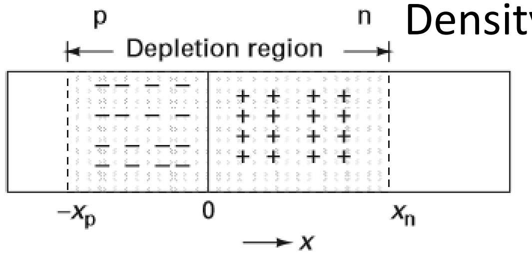
Electron, Hole Concentrations:

$$n_0 = N_c \exp\left(\frac{-(E_c - E_F)}{kT}\right)$$

$$p_0 = N_v \exp\left(\frac{-(E_F - E_v)}{kT}\right)$$

Depletion layer width (page 33):

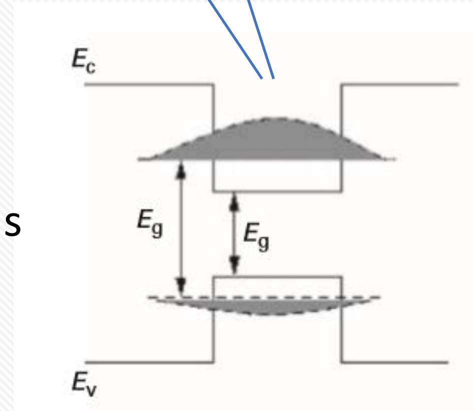
$$W = \sqrt{\frac{2\epsilon_s}{q}\left(\frac{N_D + N_A}{N_A N_D}\right)(V_{bi} \mp V_A)}.$$



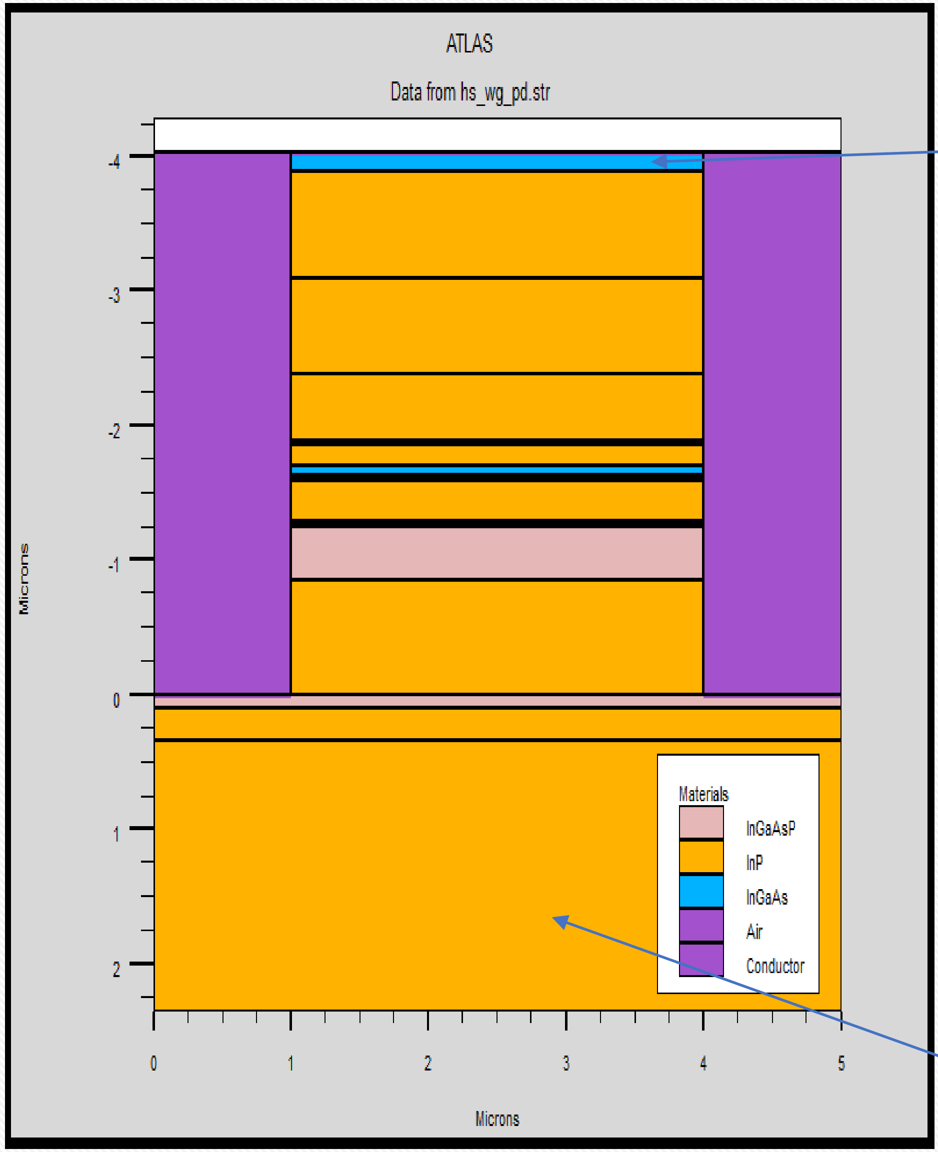
Density of States: Conduction & Valence Bands

$$g_c(E) = \frac{m_n^* \sqrt{2m_n^*(E - E_c)}}{\pi^2 \hbar^3}, \quad E \geq E_c$$

$$g_v(E) = \frac{m_p^* \sqrt{2m_p^*(E_v - E)}}{\pi^2 \hbar^3}, \quad E \leq E_v$$



Structure & Compositions



Top down layer structure:

R5	1500A	InGaAs	Zn: >1e19	**P-ohmic contact layer**/*p-cladding*
R4	8000A	InP	Zn: 1e18	*Gradual doping*
R3	7000A	InP	Zn: 7e17	
R2	5000A	InP	Zn: 5e17	……….*R: regrown layers*
R1	300A	InP	UID (unintentionally doped)	
1.	1500A	InP	Zn: 1e18	
2.	750A	InGaAs	Zn: 2e18	…………*light absorber*
3.	80A	InGaAs		
4.	160A	1.24Q		
5.	60A	InP		**UTC photodetector layers**
6.	70A	InP	Si: 1e18	……………*cleave layer – highly doped*
7.	3000A	InP	Si: 5e16	……………*lightly doped*
8.	250A	InP	Si: 2e18	
9.	150A	Barrier	Si: 5e17	
10.	150A	InP	Si: 1e18	
11	800A	Barrier	Si: 1e18	
12	4000A	1.3Q	Si: 1e18	**MQW waveguide**
14	800A	Barrier	Si: 1e18	
15.	8500A	InP	Si: 1e18	
16.	1000A	1.1Q	Si: 2e18	**N-ohmic contact layer**
17.	2500A	InP	Si: 1e18	
18.	20000A	InP	UID	

Structure & Compositions

Compositions (x,y):

$In_xGa_{1-x}As$ (x = 0.532) $In_{0.532}Ga_{0.468}As$

1.24Q
Lattice matchd (to InP) InGaAsP with bandgap corresonding to 1.24 micron photon wavelength

1.1Q
Lattice matchd (to InP) InGaAsP with bandgap corresonding to 1.1 micron photon wavelength

1.3Q
Lattice matchd (to InP) InGaAsP with bandgap corresonding to 1.3 micron photon wavelength

Barrier $In_{0.8}Ga_{0.2}As_{0.44}P_{0.56}$

Zn : P-dopant
Si : n-dopant

Lattice matching: values approximated using experimental data from publication (see reference).

$In_{1-x}Ga_xAs_yP_{1-y}$ lattice-matched to InP		
λ (μm)	X	Y
1.1	0.15	0.3
1.24	0.25	0.5
1.3	0.3	0.65

Values of band gap near transition energies, wavelengths, material and lattice mismatch of the grown samples

Sample	Material	PL energy [eV]	PL Wavelength [nm]	Thickness [nm]	Lattice mismatch [ppm]	x composition	y composition
A	InGaAs	0.737	1682	510	−120	0.46	1
B	InGaAsP	0.799	1550	425	−100	0.42	0.90
C	InGaAsP	0.857	1446	490	−250	0.38	0.79
D	InGaAsP	0.910	1363	495	+ 1800	0.32	0.69
E	InGaAsP	1.062	1168	510	−740	0.19	0.42
F	InGaAsP	1.170	1059	505	−190	0.11	0.24
G	InP	1.346	921	505	0	0	0

Sten Seifert and Patrick Runge, "Revised refractive index and absorption of $In_{1-x}Ga_xAs_yP_{1-y}$ lattice-matched to InP in transparent and absorption IR-region," Opt. Mater. Express **6**, 629-639 (2016)

```
        #Michael Benker
        #ECE530 Advanced Electronics/Optoelectronics
        #UMASSD 2/24/2020

go atlas

mesh auto
x.m l=0 Spac=0.1
x.m l=1 Spac=0.1
x.m l=4 Spac=0.1
x.m l=5 Spac =0.1


#n region
#1.1Q
region bottom  thick = 0.1            material =  InGaAsP      NY = 10  donor = 2e18     x.comp=0.15 y.comp=0.3
region bottom  thick = 0.25     material =  InP    NY = 10  donor = 1e18
region bottom  thick = 2.0      material =  InP    NY = 10


#waveguide

region top  thick = 0.85  material =  InP    NY = 10  donor = 1e18
region top  thick = 0.08  material =  InGaAsP      NY = 10  donor = 1e18     xcomp=0.2 y.comp=0.44
#1.3Q
region top  thick = 0.4  material =  InGaAsP NY = 10  donor = 1e18     x.comp=0.3 y.comp=0.65
region top  thick = 0.08  material =  InGaAsP      NY = 10  donor = 1e18     xcomp=0.2 y.comp=0.44

#field terminator

region top  thick = 0.015       material =  InP    NY = 10  donor = 1e18
region top  thick = 0.015       material =  InGaAsP      NY = 10  donor = 5e17     xcomp=0.2 y.comp=0.44


#collector

region top  thick = 0.025       material =  InP    NY = 10  donor = 2e18
region top  thick = 0.3   material =  InP    NY = 10  donor = 5e16
region top  thick = 0.007       material =  InP    NY = 10  donor = 1e18


#band smoothing

region top  thick = 0.006       material =  InP    NY = 10
#1.24Q
region top  thick = 0.016       material =  InGaAsP      NY = 10   x.comp=0.25 y.comp=0.5


region top  thick = 0.008       material =  InGaAs NY = 10
region top  thick = 0.075       material =  InGaAs NY = 10  acceptor = 2e18


#p-cladding

region top  thick = 0.15        material =  InP    NY = 10  acceptor = 1e18


#regrowth layers

region top  thick = 0.03        material =  InP    NY = 10
region top  thick = 0.5   material =  InP    NY = 10  acceptor = 5e17
region top  thick = 0.7   material =  InP    NY = 10  acceptor = 7e17
region top  thick = 0.8   material =  InP    NY = 10  acceptor = 1e18

#p-contact

region top  thick = 0.15        material =  InGaAs NY = 10  acceptor = 1e19
```

```
#etch

region  mat = air  x.min =  0 x.max = 1  y.max = 0
region  mat = air  x.min = 4 x.max = 5  y.max = 0

#electrode

electrode name=gate x.min = 1 x.max = 4 top
electrode name=np x.min=0 x.max=1 y.max = 0 y.min = 0
electrode name=np x.min=4 x.max=5 y.max = 0 y.min = 0

contact name=gate resistance = 50


#Materials

material material=InGaAsP taun0=20.e-9 taup0=33e-9 \
  align=0.4 real.index=3.4 imag.index=0

material material=InGaAs taun0=0.7e-9 taup0=33e-9 \
 real.index=3.43 imag.index=0.2

material  material=InP   taun0=2e-9 taup0=33e-9 \
 align=0.4 real.index=3.17 imag.index=0

#model

models fldmob srh optr fermidirac conmob print EVSATMOD=1

mobility material = InP mun=4917.0 mup=150.0 vsatn =  2.6e7 vsatp = 0.66e7 ecritn=11e3 ecritp=4e3 gamman=4 gammap=1
mobility material = InGaAs  mun=11599.0 mup=331.0 vsatn = 2.5e7 vsatp=0.5e7 ecritn=3e3 ecritp=4e3 gamman=4 gammap=1
mobility material = InGaAsP mun=4600.0 mup=150.0  vsatn = 2.68e7 vsatp=0.6e7 ecritn=6e3 ecritp=4e3 gamman=4 gammap=1

#solving

solve  init outf = sol_hswgpd.str
load inf = sol_hswgpd.str

LOG outf=hs_wg_pd_f.log

solve vgate=0.2 vstep=0.2 vfinal=4 name="gate"
tonyplot hs_wg_pd_f.log

log off

solve  init outf = sol_hswgpd.str
load inf = sol_hswgpd.str
LOG outf=hs_wg_pd_r.log

solve vgate=-0.2 vstep=-0.2 vfinal=-4 name="gate"

tonyplot hs_wg_pd_r.log

log off

output band.param photogen opt.intens con.band val.band

save outf=hs_wg_pd.str

tonyplot hs_wg_pd.str

#tonyplot sol_hswgpd.str

quit
```