Extremely Time-consuming Project Presentation

2023.5.15

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Content

Fiber Optic Communication

APD Area Review

Paper Reproduction

Content

APD Area Review

- Noise and Main parameters
- $In_{0.53}Ga_{0.47}As$
- SACM APD
- Ge/Si APD
- Reduce the thickness of the multiplier layer
- $In_{0.52}Al_{0.48}As$
- Three mesa
- Two-layer absorption
- Impact Ionization Engineering
- Longer wavelength

Content

Paper Reproduction

- Determination of basic parameters
  - Electrical field
  - Workmanship
  - Ohmic contact
  - Graded band
  - Initial value
- Simulation attempt
  - N17
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- Dual Charge Layers
  - Theoretical analysis
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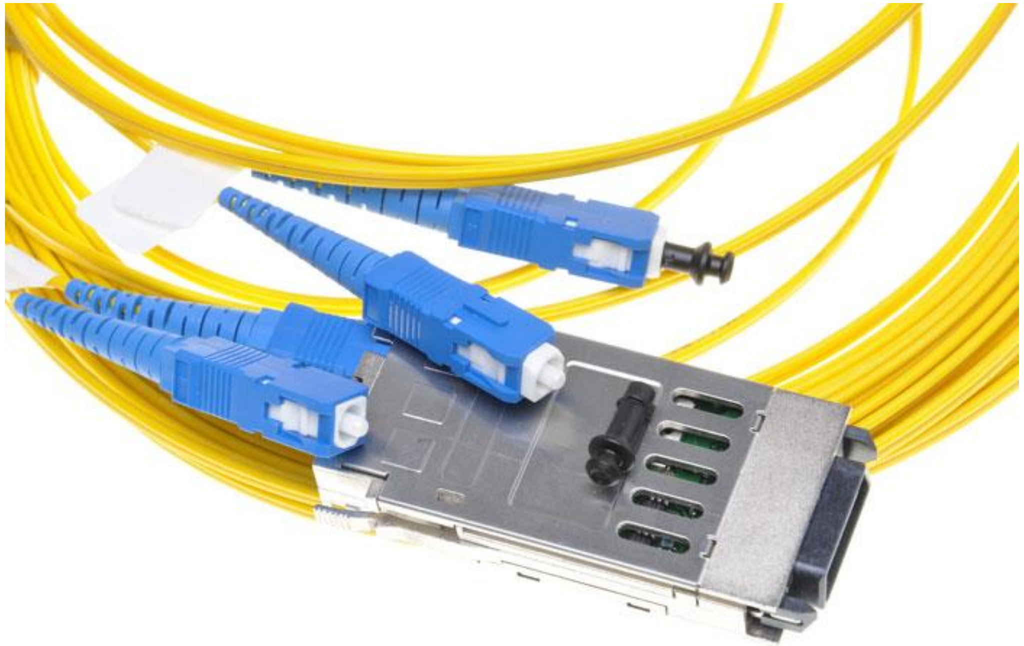
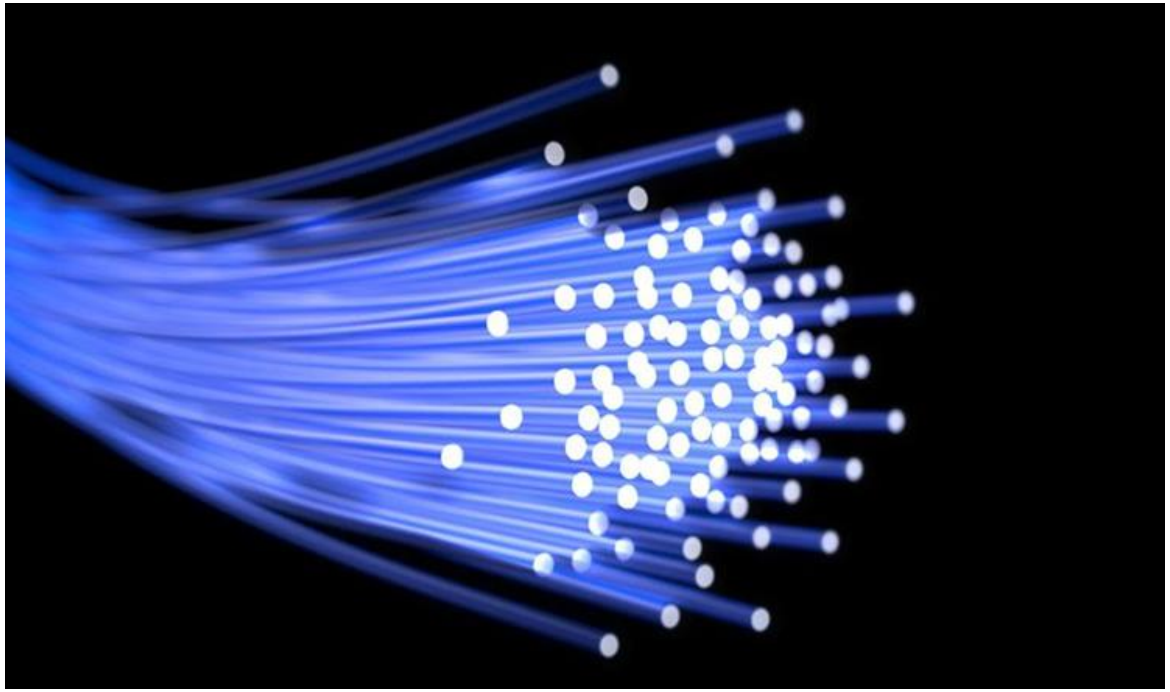
  - P13
- Three mesa
  - Structure B comparison
  - Structure C comparison
- Reliability
  - Unintentional doping
  - Gradient problem
- Current dependent
  - Dark current
  - Light current

Fiber Optic Communication





Reducing loss

Silicon Dioxide

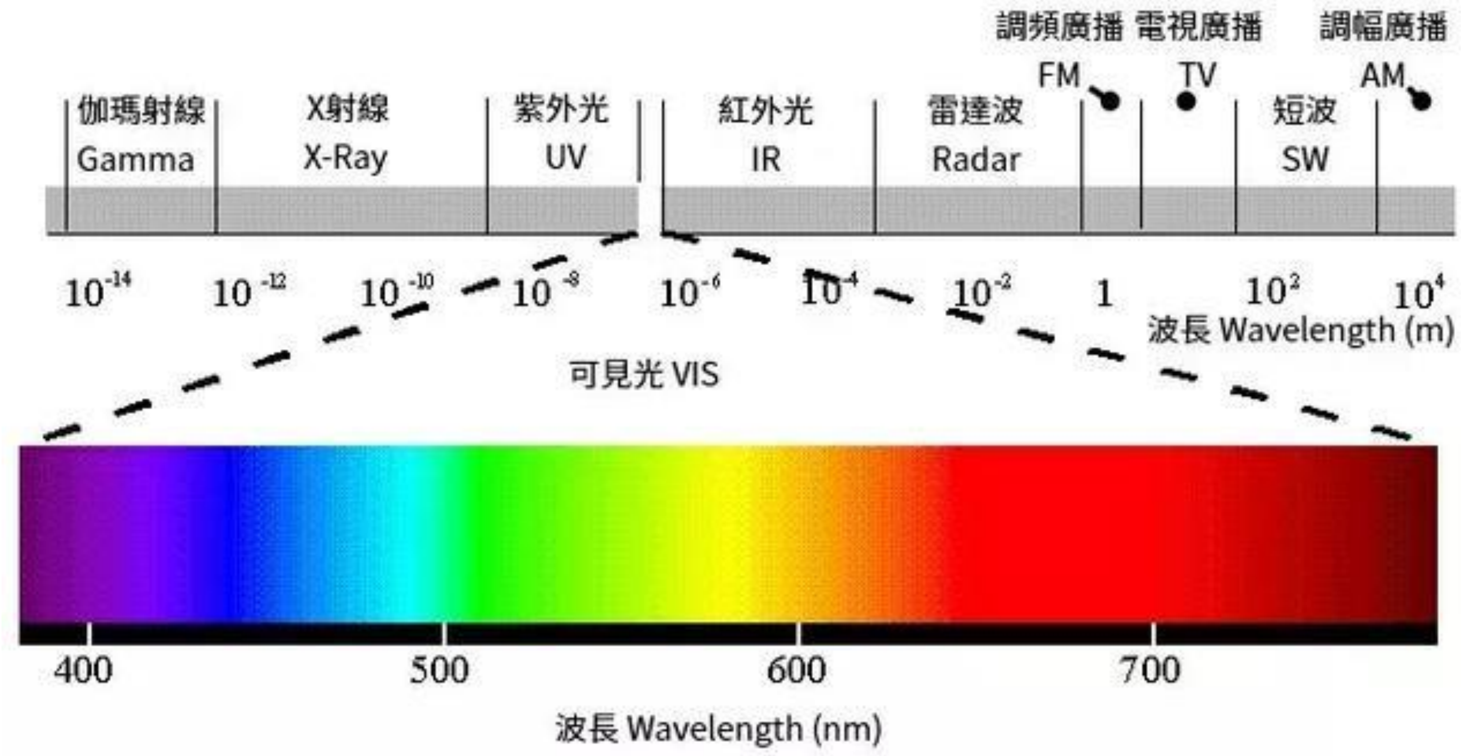
SiO_2 absorption

- optical transparency
- mechanical strength
- electromagnetic interference resistance
- cost-effectiveness

Silicon Dioxide

SiO_2 light absorption

- bonding electrons
- vibration mode of the Si-O bond network



Silicon Dioxide

Scattering

short-wavelength

Rayleigh scattering

high light intensity

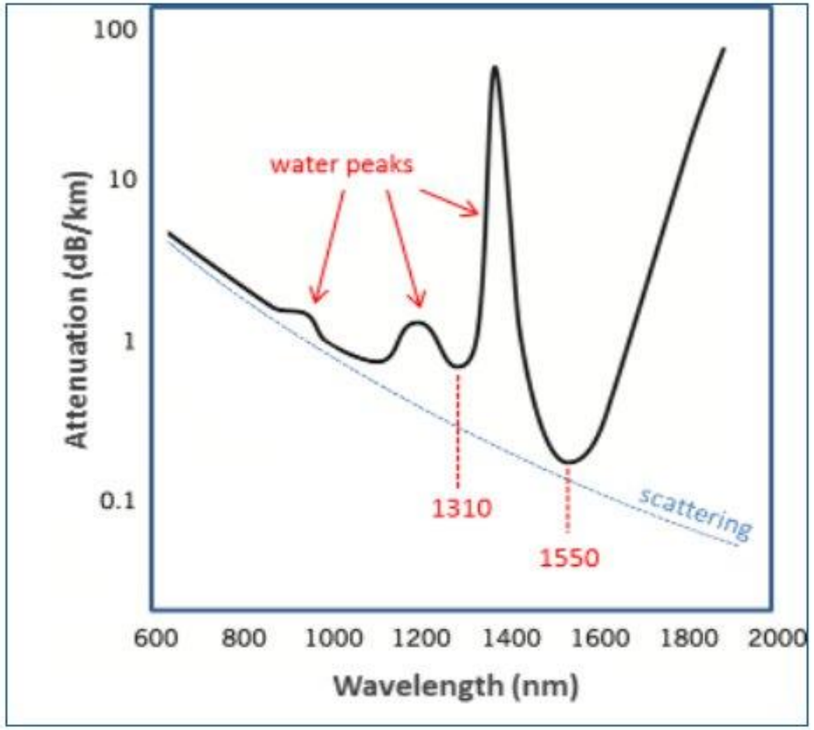
spontaneous Raman scattering

brillouin scattering

[1] https://www.sohu.com/a/580776421_120733531

Water Vapor

water vapor light absorption



[1] Carter, G.A. (1993). "Relationship of leaf spectral reflectance to chloroplast water content determined using NMR microscopy". Remote Sensing of Environment. 46 (3): 305–310.
[2] Rossel, R.A.V. (1998). "Laboratory evaluation of a proximal sensing technique for simultaneous measurement of soil clay and water content". Geoderma. 85 (1): 19–39.

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- $In_{0.53}Ga_{0.47}As$
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- Longer wavelength

Recent Advances in Avalanche Photodiodes

Joe C. Campbell, *Fellow, IEEE*

(Invited Paper)

Performance Index

Noise
- Thermal noise
- Particle noise

Core Index
- Gain
- Bandwidth
- Gain-bandwidth product
- Excess noise factor

$In_{0.53}Ga_{0.47}As$

Advantage

Bandgap: 0.79eV

$$0.79eV \approx \frac{hc}{e \cdot 1510nm}$$

Lattice constant: 5.868Å

matching well with InP

[4] Cook, L. W. Electron and hole impact ionization coefficients in InP determined by photomultiplication measurements[J]. Applied Physics Letters, 1982, 40(7): 589-591.

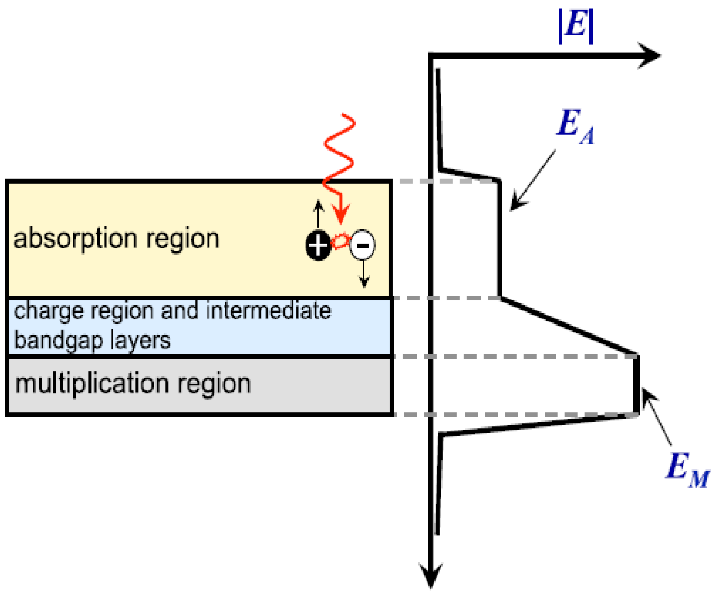
InP

InP

- Low dark current
- Pure hole carrier
- Low noise

$$I=\frac{(2m^{*})^{1/2}q^{3}EVA}{4\pi^{2}\hbar^{2}\epsilon_g^{1/2}}\exp\left(-\frac{\theta m_0^{1/2}\epsilon_g^{3/2}}{q\hbar E}\right).$$

SACM APD



relatively weak absorption efficiency

↓

an absorption layer of at least 2.5 μm

↓

longer transition time

↓

lower Gain–bandwidth product

SACM APD

Disadvantage

- low Gain–bandwidth product
- Produce more noise than Si
- Cannot be integrated with the silicon based CMOS process
- Expensive
- Poor crystal quality
- Complex manufacturing process

Ge/Si

Absorption region Ge

Multiplication region Si

- Wavelength is calculated to be 1.1 μm
- Low absorption efficiency near the cutoff wavelength
- Lattice mismatch

[5] Shah V A, et al. Effect of layer thickness on structural quality of Ge epilayers grown directly on Si(001)[J]. Thin Solid Films, 2011, 519(22): 7911-7917.

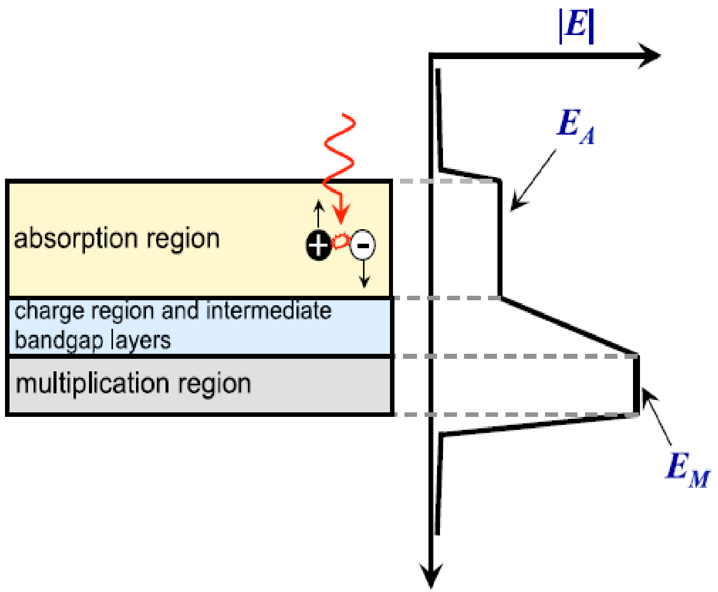
Lattice Mismatch

Lattice mismatch

- Rough surface of Ge
- High density of dislocation defects
- Dark current
- Power consumption
- Noise

[6] Masini G, et al. High responsivity near infrared Ge photodetectors integrated on Si[J]. Electronics Letters, 1999, 35(17): 1467-1468.
[7] Wei Y, et al. Analysis of dark current dependent upon threading dislocations in Ge/Si heterojunction photodetectors[J]. Microelectronics International, 2012, 29(3): 136-140.

Multiplication layer thickness



$$l = \tau \cdot v \approx 43nm$$

$In_{0.52}Al_{0.48}As$

$$I = \frac{(2m^*)^{1/2} q^3 EVA}{4\pi^2 \hbar^2 \epsilon_g^{1/2}} \exp\left(-\frac{\theta m_0^{1/2} \epsilon_g^{3/2}}{q\hbar E}\right).$$

bandgap 1.437 eV

matching lattice constant

Replace InP

As multiplication layer

Reduce noise

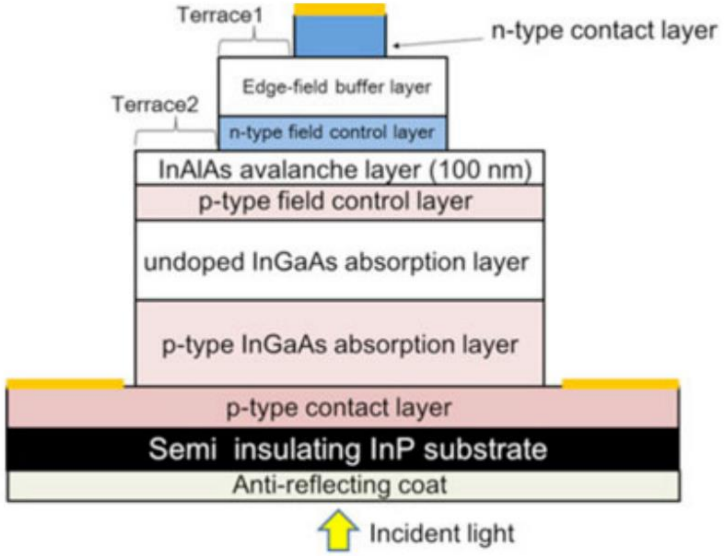
Three mesa

high electric field region is limited to the space directly below the top surface

avoiding the need for a guard ring

reduces the electric field at the edges

preventing edge breakdown and surface current leakage



Two absorption region

partially depleted p+

+

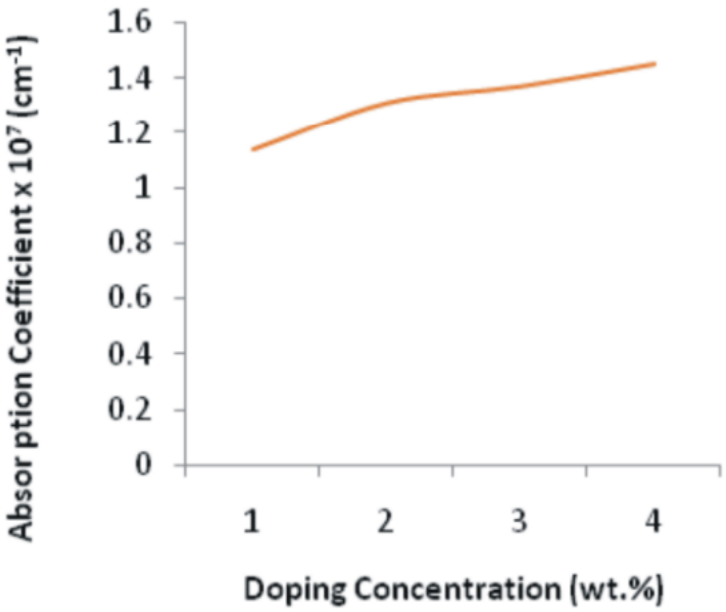
i-type depleted

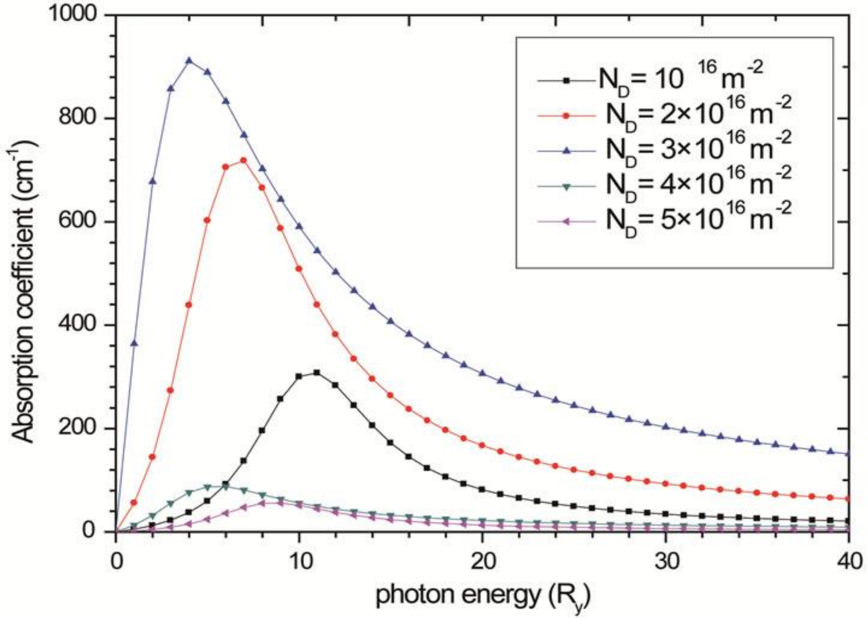
Increasing electric field

Enlarging gain

Increasing absorption efficiency

Two absorption region





[8] Alpha, M. & Daniel, Thomas. (2015). Effect of Doping Concentration on the Electrical and Optical Properties of Zn: SnO 2. IOSR Journal of Applied Physics. 7. 38-44. 10.9790/4861-07323844..
[9] Dakhlaoui, H. (2012) Effect of the Doping Layer Concentration on Optical Absorption in Si δ-Doped GaAs Layer. Optics and Photonics Journal, 2, 140-144. doi: 10.4236/opj.2012.23020.

Impact Ionization Engineering

I2E

- Materials with smaller bandgap width
- Cascade low-noise gain regions

→ Enhance higher-ionization-rate carrier collision ionization

Bigger Wavelength

Capacity crunch

↓

Increasing the bandwidth of optical fiber transmission system

↓

More data can be transmitted on same infrastructure

Bigger Wavelength

WDM

(Wavelength Division Multiplexing)

- Higher transmission capacity
- Improving data transmission efficiency

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Electrical field

$In_{0.52}Al_{0.48}As$

$\epsilon_s \approx 12.46\epsilon_0$

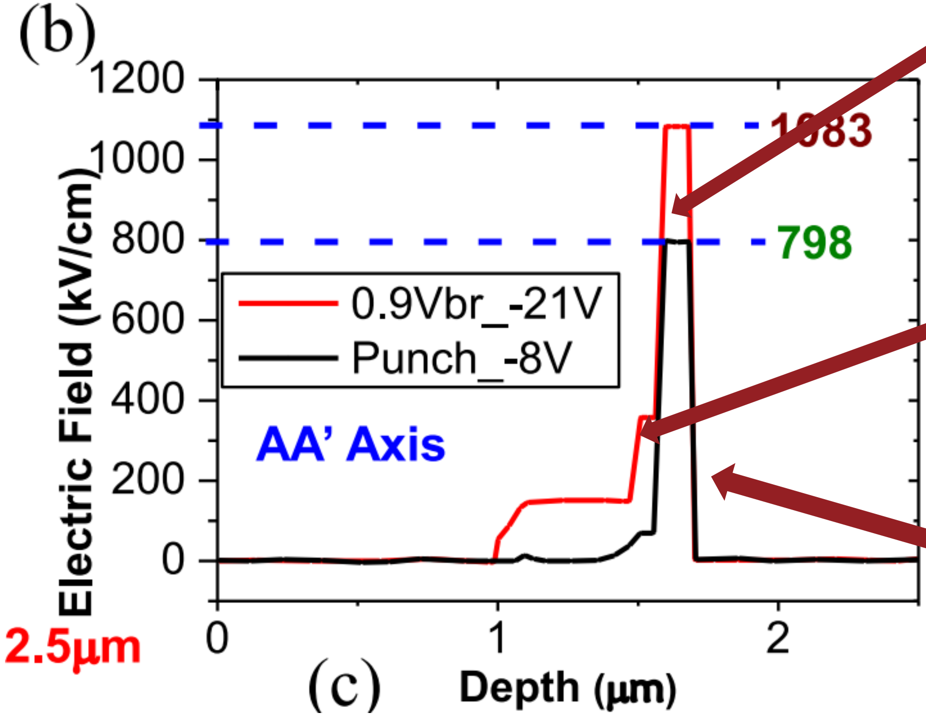
$$\frac{eN_{p13}}{\epsilon} \approx \frac{200kV/cm}{30nm}$$

$$\Rightarrow N_{p13} \approx 4.5905e17$$

$$\frac{eN_{p15}}{\epsilon} \approx \frac{700kV/cm}{30nm}$$

$$\Rightarrow N_{p15} \approx 1.6067e18$$

$$N_{n17} \geq N_{p15} \approx 1.6067e18$$



[10] M. Littlejohn, K. Kim, and H. Tian, ``High-Field Transport in InGaAs and Related Heterostructures,'' in Bhattacharya, section 4.2, pp. 107-116.

Workmanship

IntelliEPI

IntelliEPI: InP-based Production MBE HBT Development

Advantages of MBE for InP-based HBT growth

- ***High p-doping to 1E20 cm-3 and high n-doping to 5E19 cm-3***
- ***Excellent thickness and interface control***
- ***Easy to install various sensors for real-time monitoring***
- ***Low background doping***
- ***Low safety overhead***

IntelliEPI's Approaches in HBT development

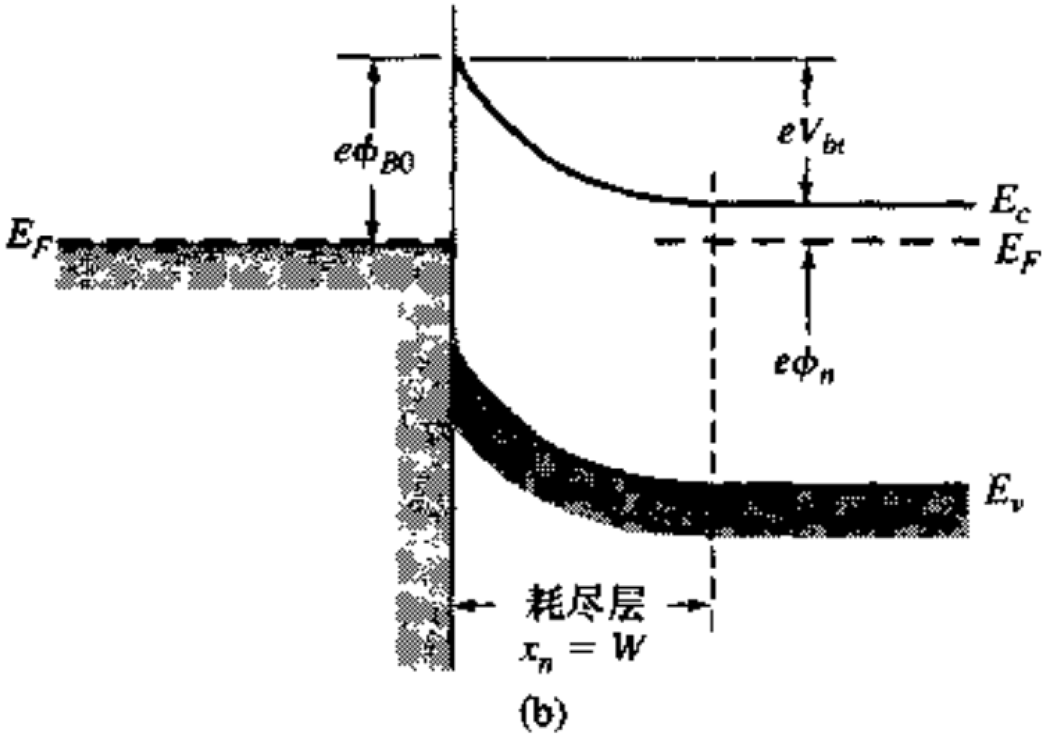
• Used multi-wafers 4x4in production MBE systems (9x4in)	12/99
• Installed sensors to monitor composition, temp., and surface	01/00
• Demonstrated reproducible and efficient P-cell operation	03/00
• Established safety protocol in P-MBE system R&M	06/00
• Delivered volume InP-based structures to customers	06/00
• Correlated processing results with in situ data	12/00
• Improved epitaxial growth based on correlations	03/01

YCKao.et al CSMAX 07/01 — www.intelliepi.com — Intelligent Epitaxy Technology, Inc.

$$N_A \leq 10^{20} cm^{-3}$$

$$N_D \leq 5 * 10^{19} cm^{-3}$$

Ohmic Contact



$$E_c - E_F = kT \ln(\frac{N_c}{N_d})$$

$$R_c \propto e^{\frac{2\sqrt{\epsilon_s m_n^*}}{\hbar}\frac{\phi_{B0}-\phi_n}{\sqrt{N_d}}}$$

Graded Band

上海科技大学
ShanghaiTech University

four $In_{0.52-x}Al_xGa_yAs_{0.48-y}$ based bulk layers with a fixed layer thickness as 3 nm and four different bandgap wavelengths at 1, 1.2, 1.4, and 1.6 μm, respectively. Such design can minimize the probability of hole trapping in the interface of hetero-structures with bandgap discontinuity, which is an issue for APD operated at the high-gain and high-power regimes [17]. High-power performance is an important characteristic for the modern APD based receiver under burst-mode operation [6], which needs to tolerate the significant variation in the launched optical power and sustain the high-speed performance.

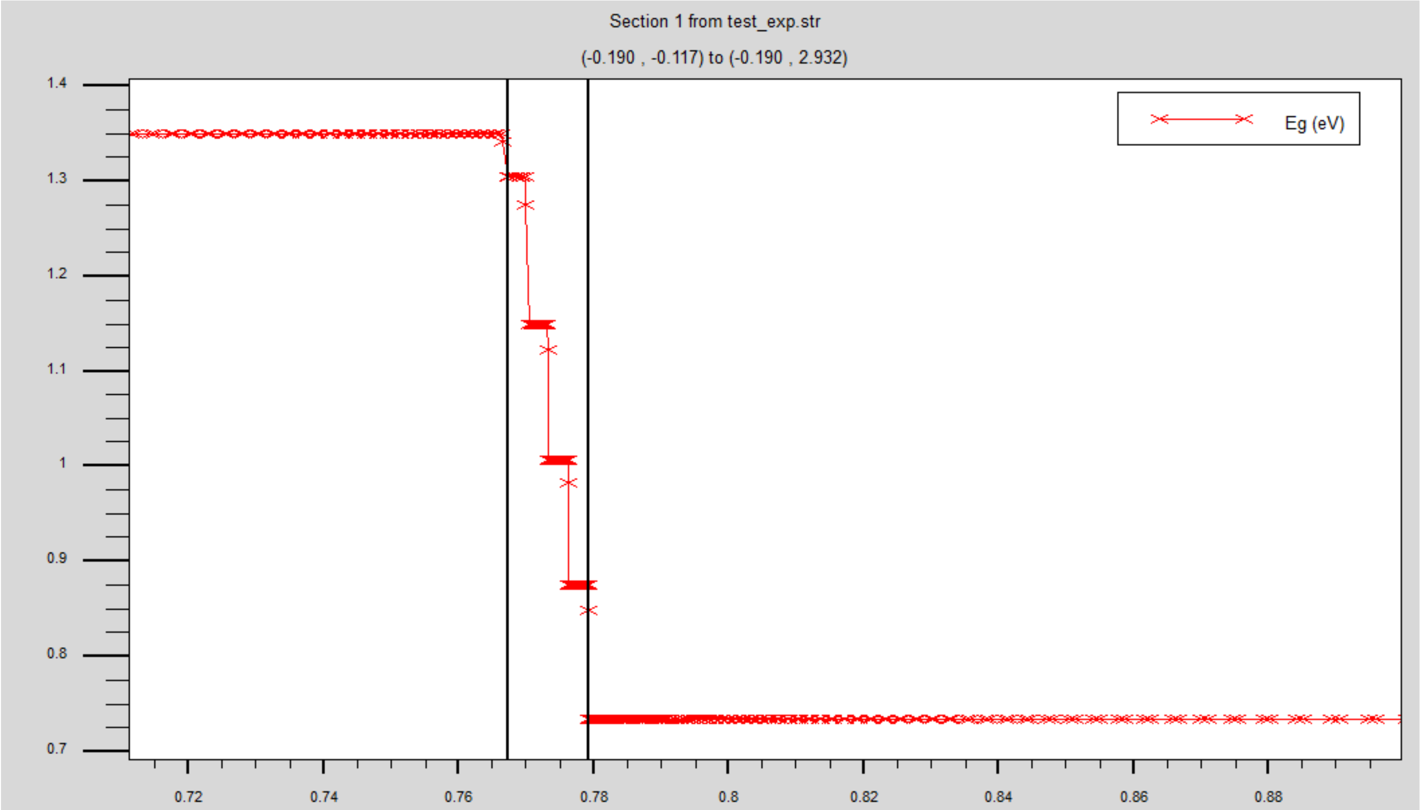
$$In_x(Al_yGa_{1-y})_{1-x}As$$

$$1.519+1.36y-1.584x+0.55xy+0.22y^2+0.475x^2$$

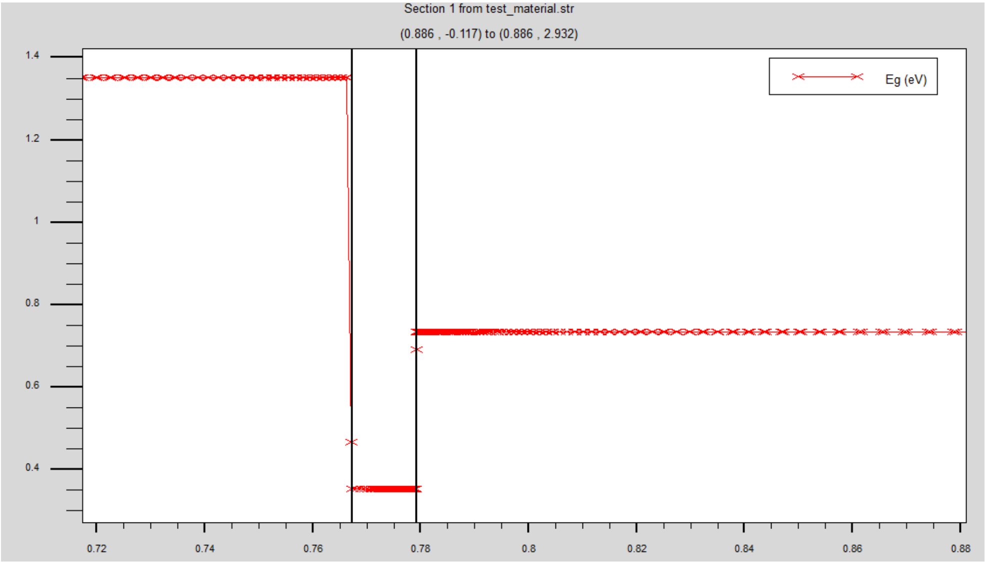
Material	Wavelength(um)
In0.61Al0.04Ga0.35As	1
In0.58Al0.03Ga0.39As	1.2
In0.55Al0.06Ga0.39As	1.4
In0.52Al0.12Ga0.36As	1.6

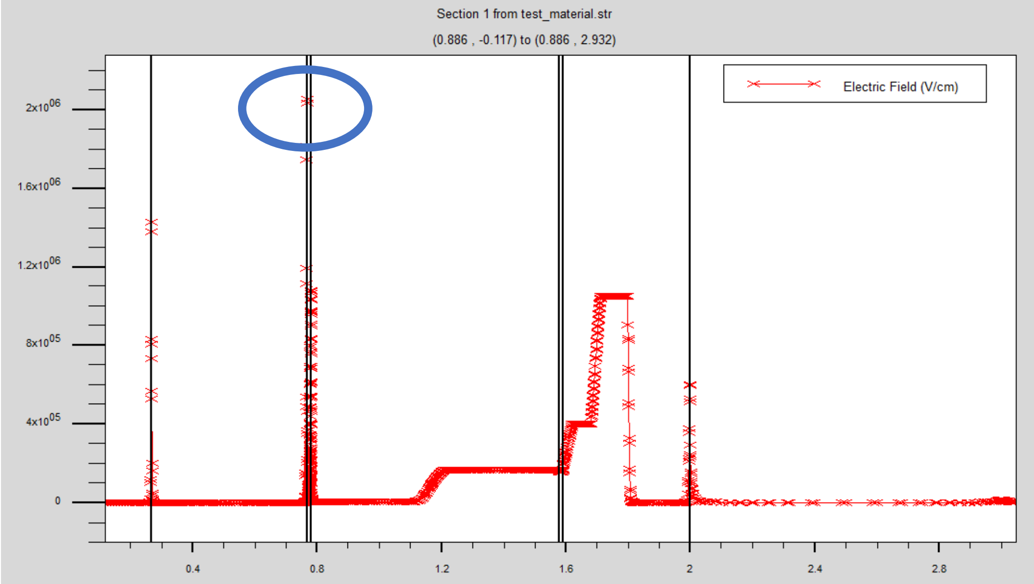
Graded Band

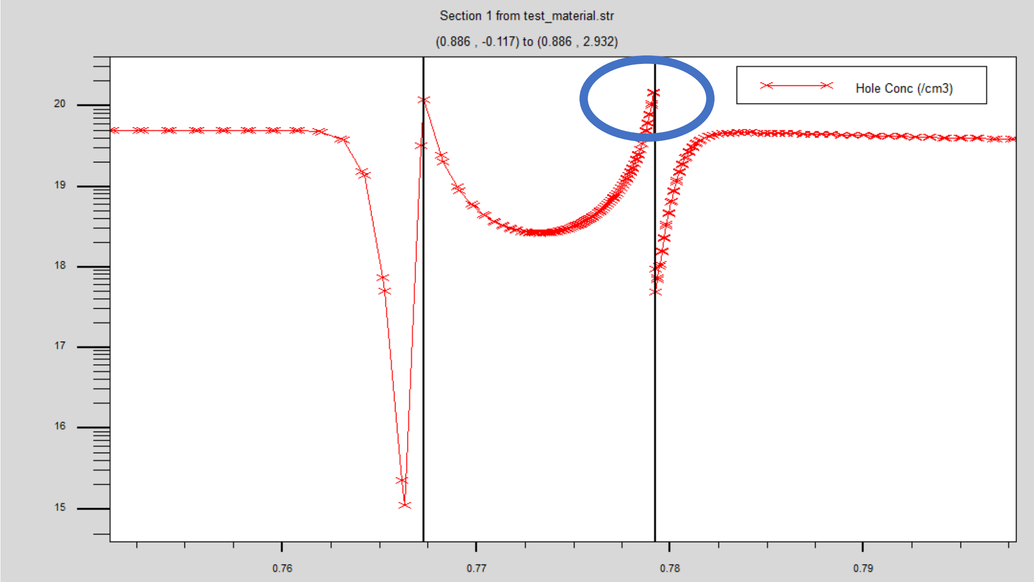
Material	Wavelength(um)
In0.2Al0.500Ga0.300As	1
In0.2Al0.367Ga0.433As	1.2
In0.2Al0.234Ga0.566As	1.4
In0.2Al0.100Ga0.700As	1.6



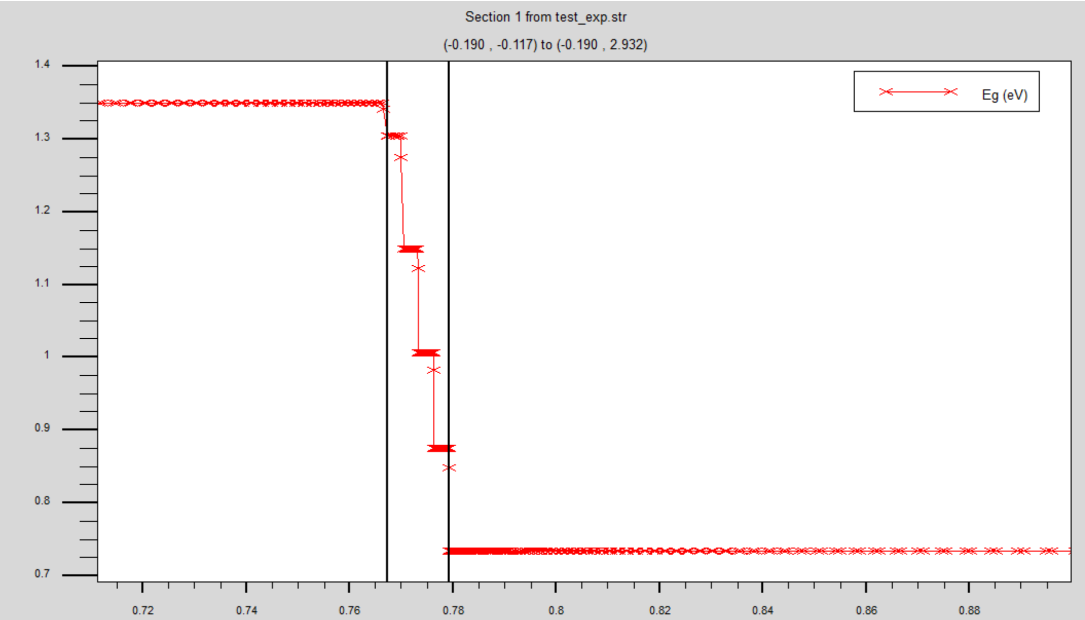
Discontinuity of Eg

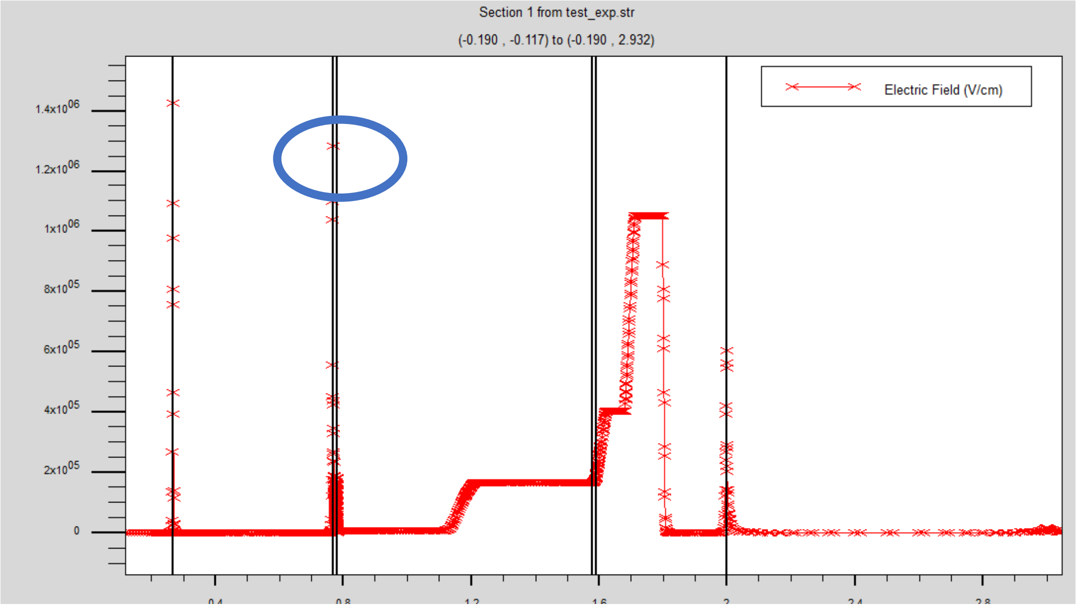


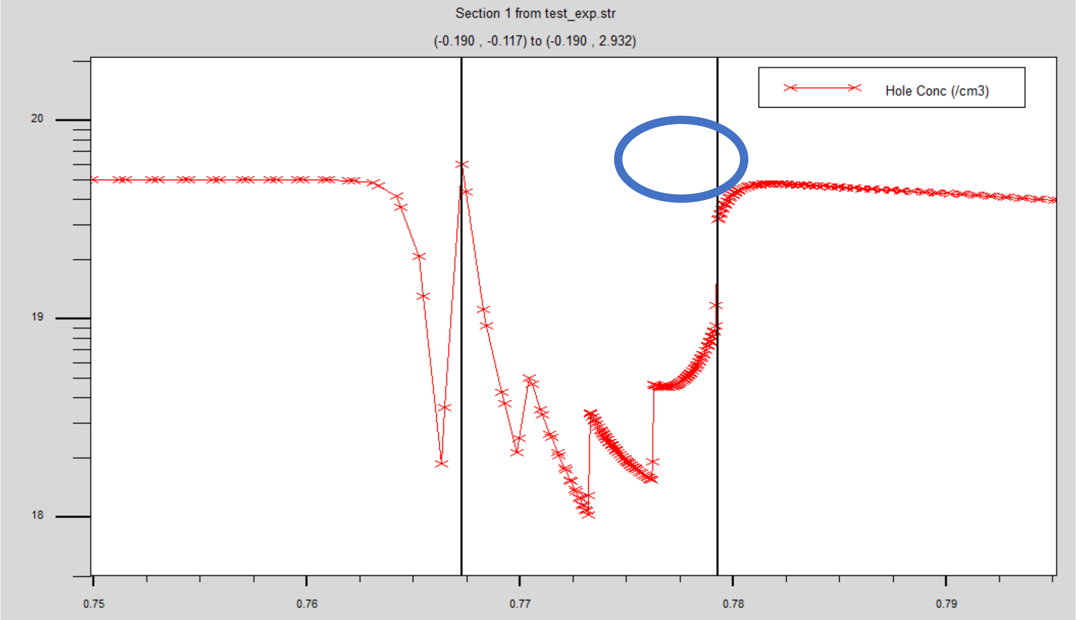




Continuity of Eg

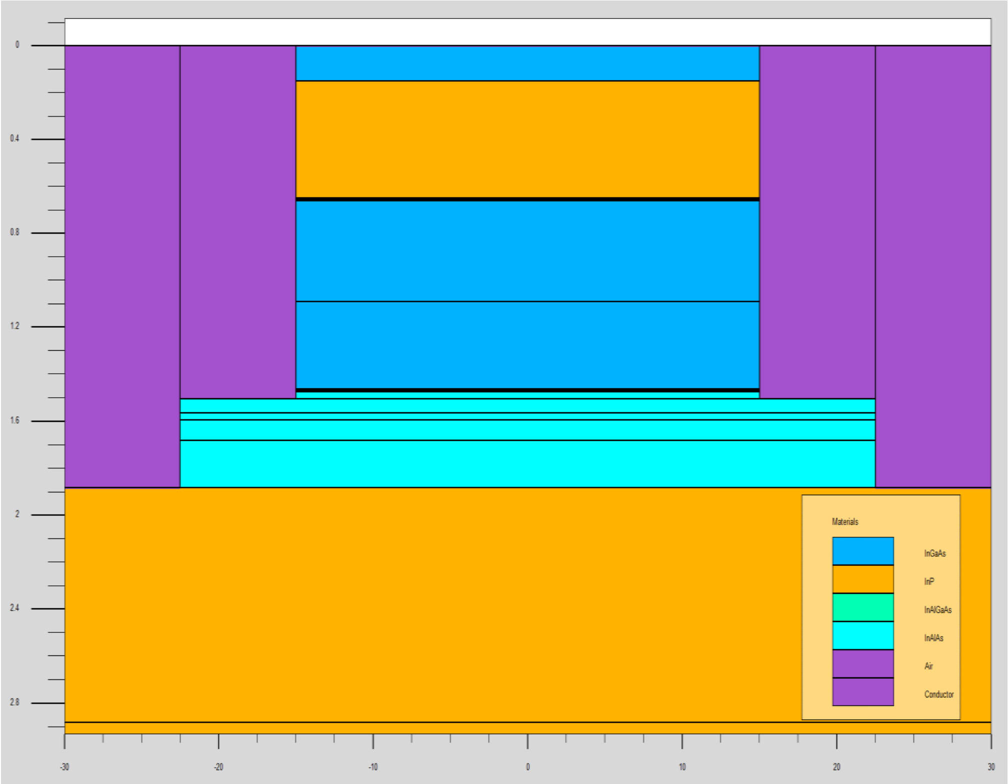




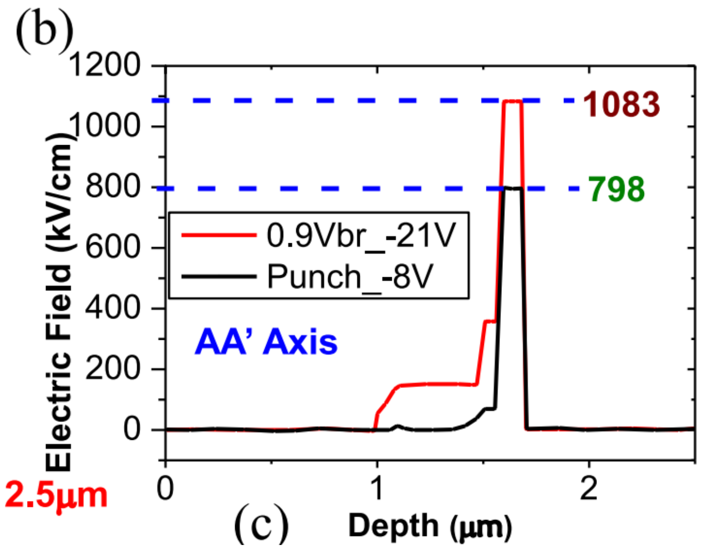


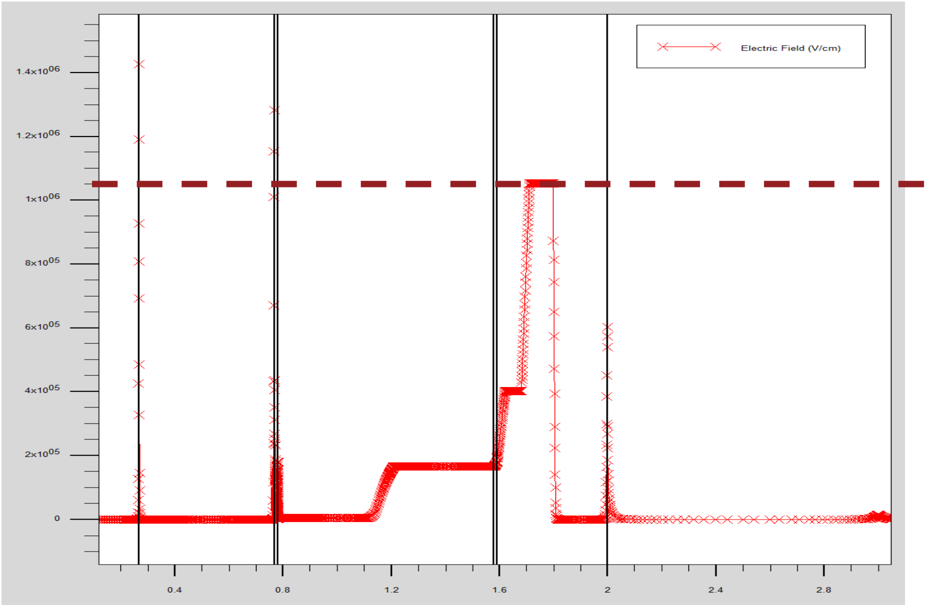
Initial Value

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

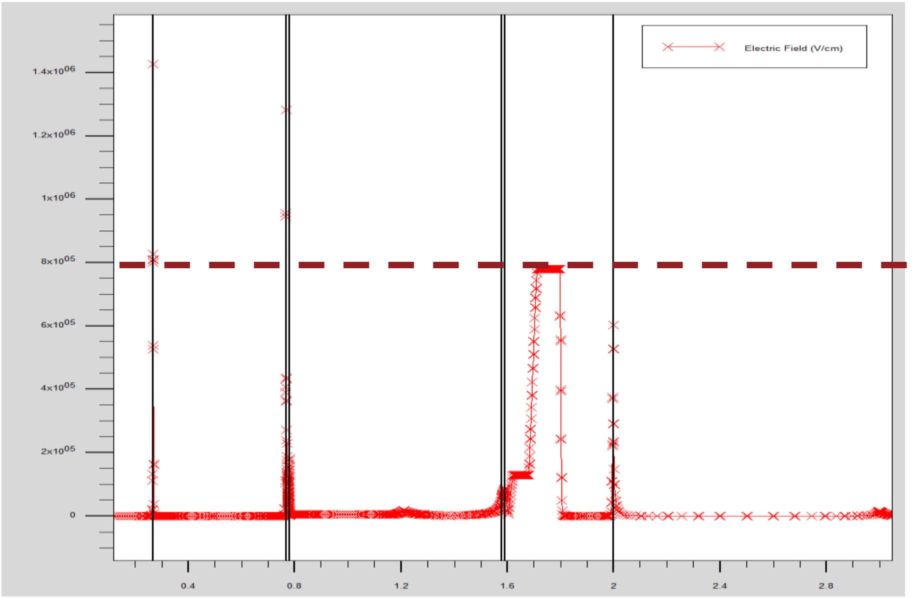


Initial Value



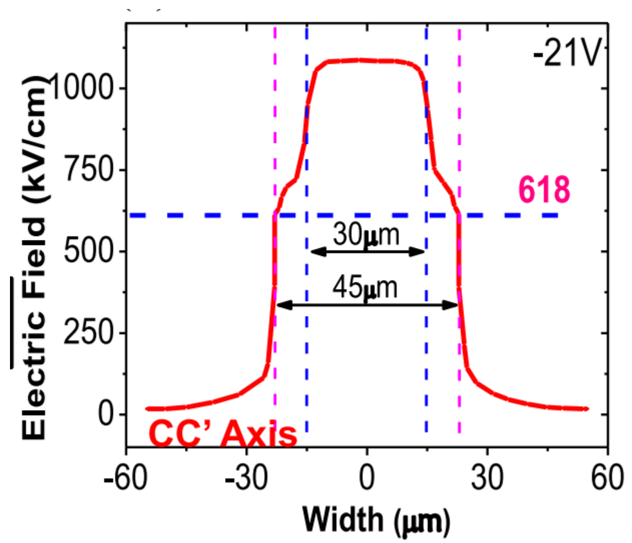


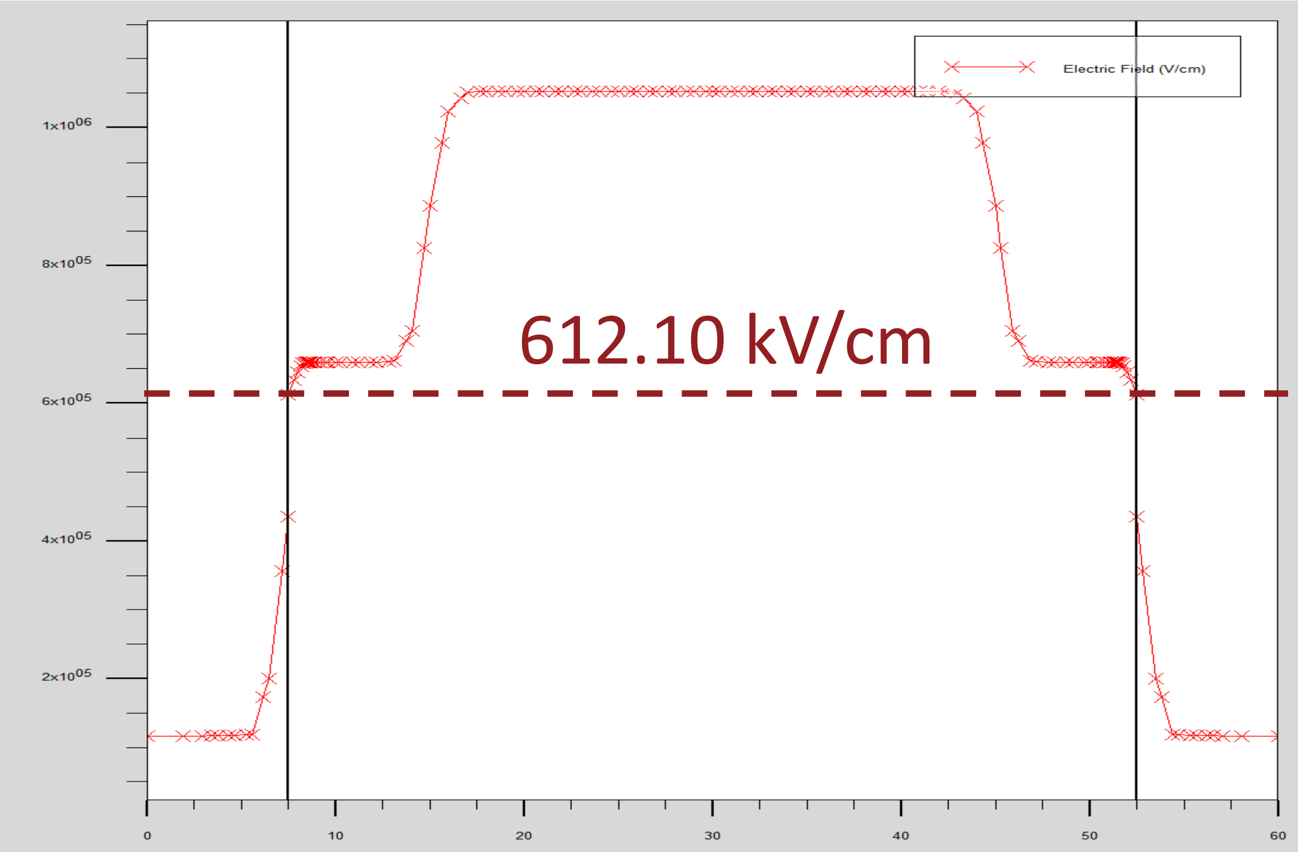
0.9Vbr_-21V:
1052.6 kV/cm



Punch_-8V:
779.88 kV/cm

Initial Value

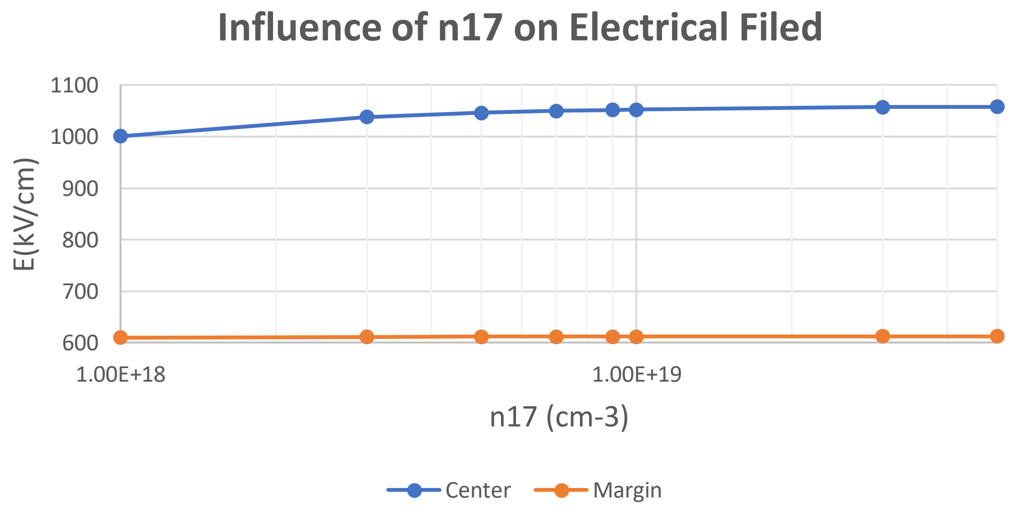




n17

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	5.00E+19	3
4	In0.2Al0.367GaAs	p-	Graded Band	5.00E+19	3
5	In0.2Al0.234GaAs	p-	Graded Band	5.00E+19	3
6	In0.2Al0.100GaAs	p-	Graded Band	5.00E+19	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	3
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	0
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	n17	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

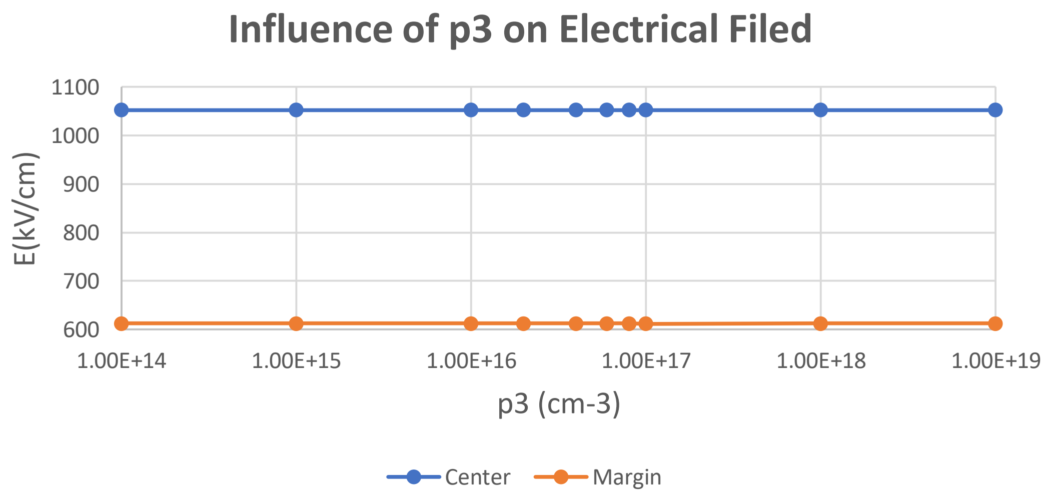
n17	1.00E+18	3.00E+18	5.00E+18	7.00E+18	9.00E+18	1.00E+19	3.00E+19	5.00E+19
Center	1001.1	1038.1	1046.2	1049.8	1051.8	1052.6	1057.1	1058.1
Margin	610.14	611.62	612.02	611.98	612.18	612.12	612.4	612.52



p3

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	p3	3
4	In0.2Al0.367GaAs	p-	Graded Band	p3	3
5	In0.2Al0.234GaAs	p-	Graded Band	p3	3
6	In0.2Al0.100GaAs	p-	Graded Band	p3	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

p3	1.00E+14	1.00E+15	1.00E+16	2.00E+16	4.00E+16	6.00E+16	8.00E+16	1.00E+17	1.00E+18	1.00E+19
Center	1052.6	1052.6	1052.6	1052.6	1052.6	1052.6	1052.6	1052.6	1052.6	1052.6
Margin	612.16	612.18	612.2	612.22	612.14	612.26	612.2	612.12	612.18	612.24



n18

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	1.00E+17	3
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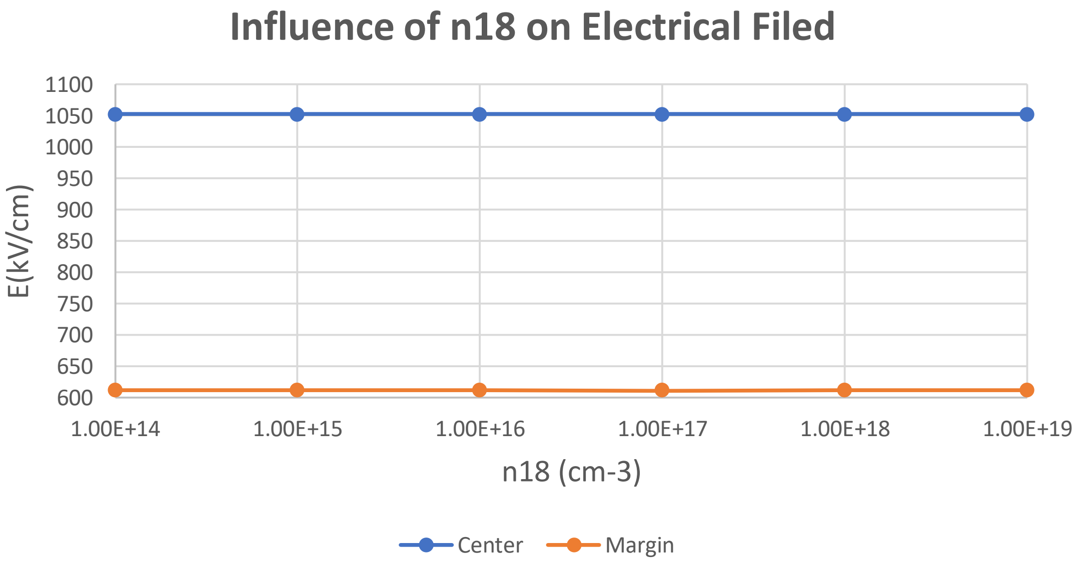
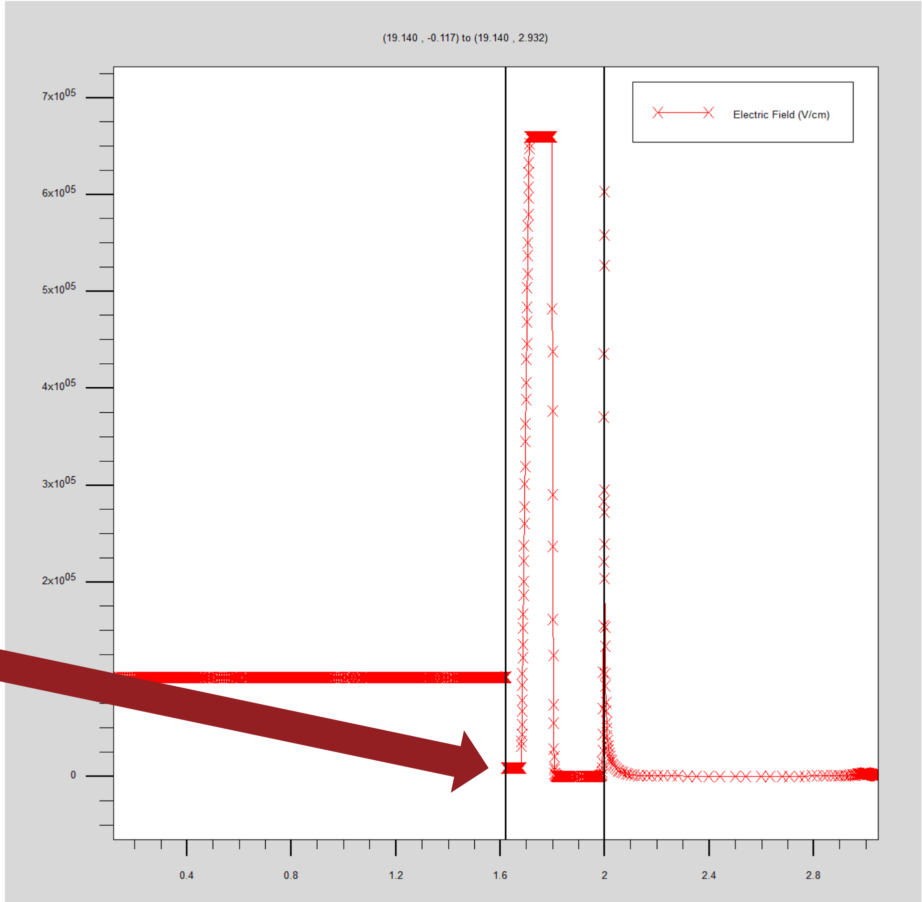
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	6[illegible]
15	In0.52Al0.48As	p+	Charge	1.50E+18	[illegible]0
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	n18	1000
19	InP	I-	Buffer	0.00E+00	50

n18	1.00E+14	1.00E+15	1.00E+16	1.00E+17	1.00E+18	1.00E+19
Center	1052.6	1052.6	1.05E+03	1.05E+03	1052.6	1052.6
Margin	612.21	612.12	612.24	612.03	612.24	612.14



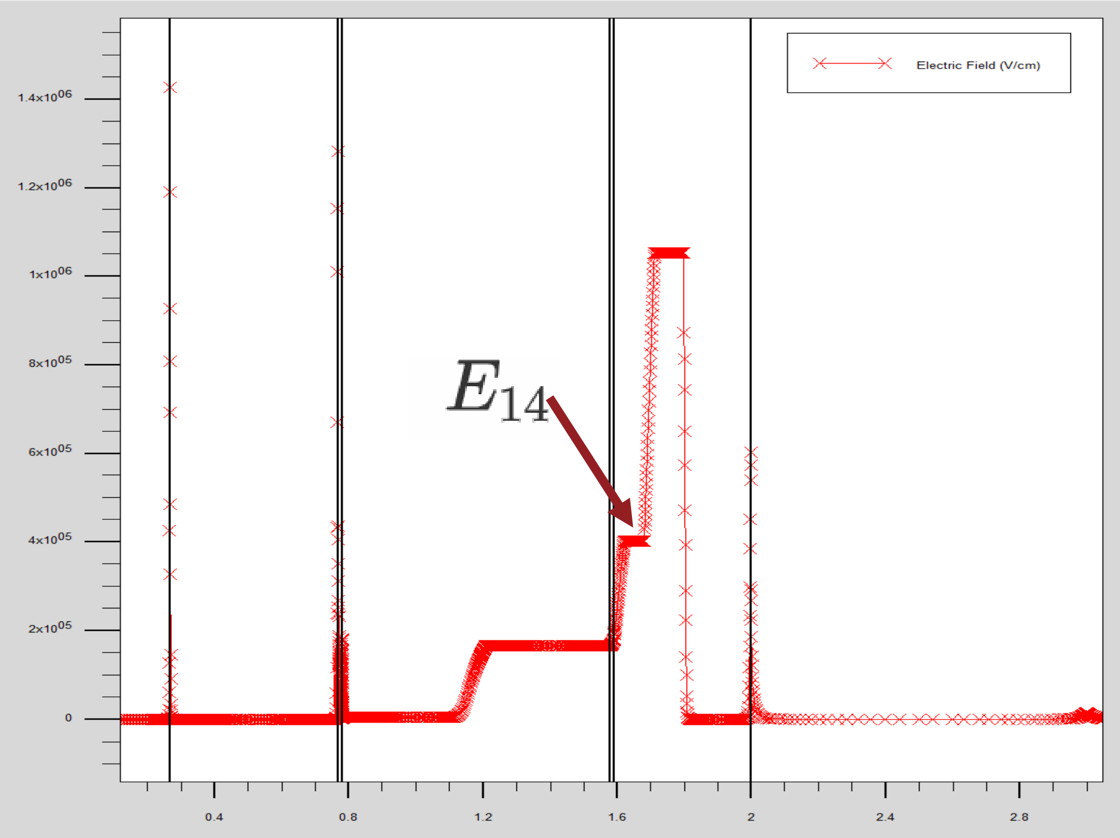
Dual charge layer

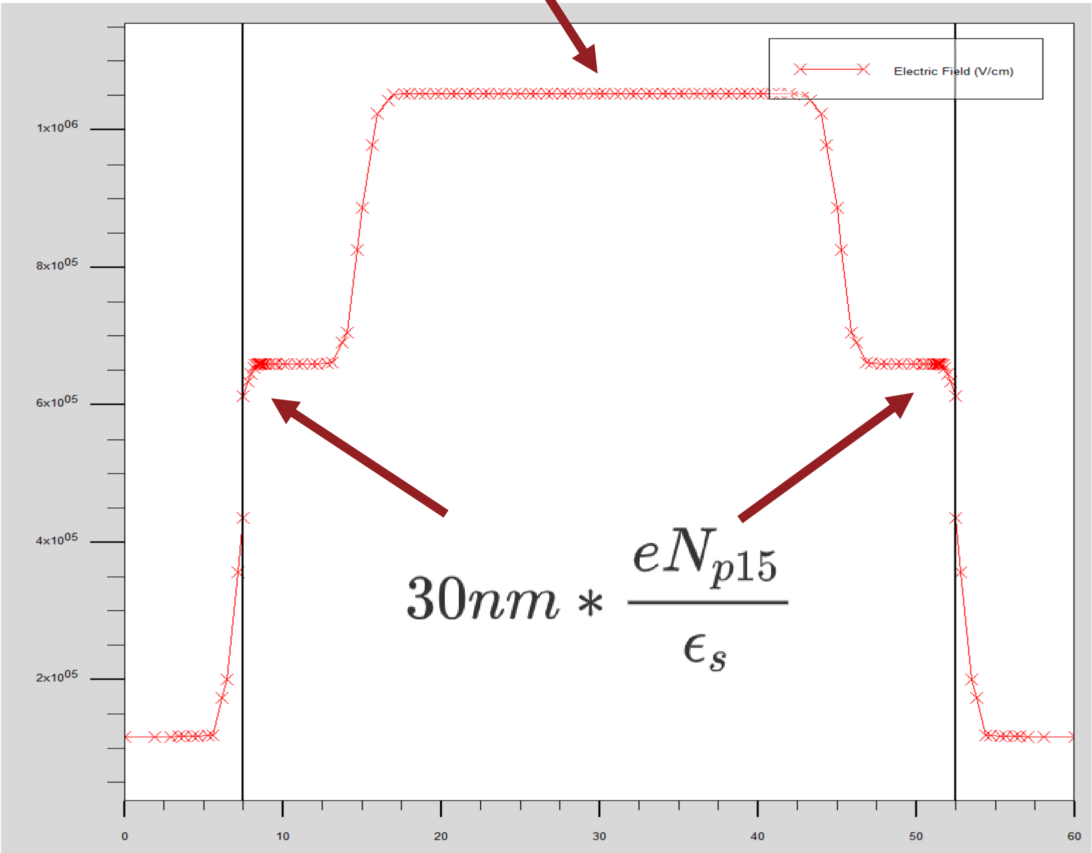
Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50



Dual charge layer

$$E_{14} + 30nm * \frac{eN_{p15}}{\epsilon_s}$$

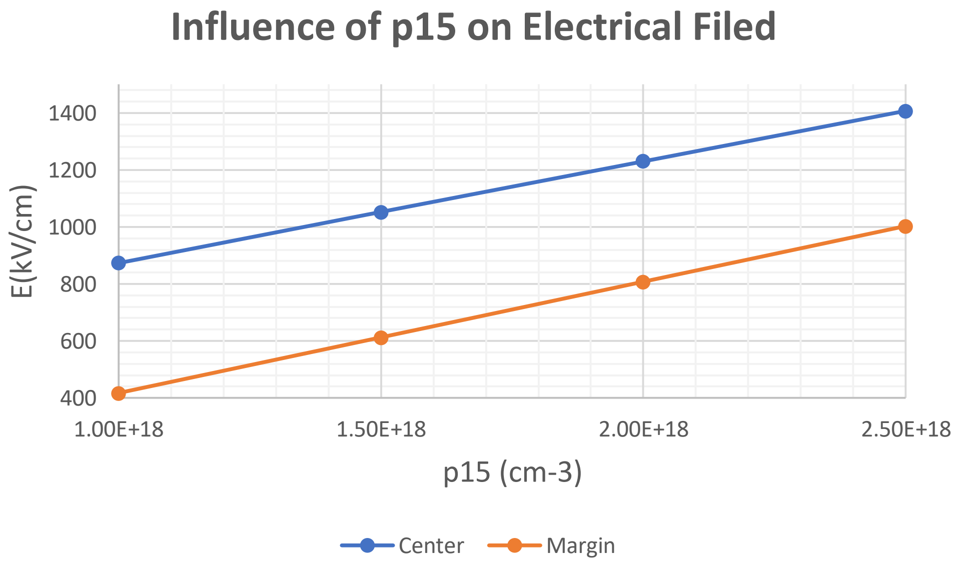




p15

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	1.00E+17	3
4	In0.2Al0.367GaAs	p-	Graded Band	1.00E+17	3
5	In0.2Al0.234GaAs	p-	Graded Band	1.00E+17	3
6	In0.2Al0.100GaAs	p-	Graded Band	1.00E+17	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	p15	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+17	1000
19	InP	I-	Buffer	0.00E+00	50

p15	1.00E+18	1.50E+18	2.00E+18	2.50E+18
Center	873.6	1052.6	1.23E+03	1407.8
Margin	416.6	612.22	807.62	1003.1



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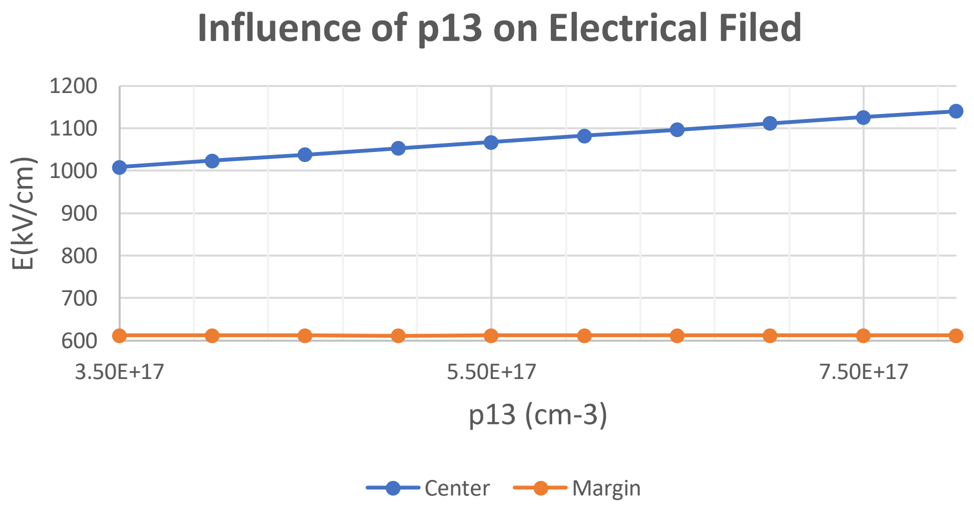
p13

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	1.00E+17	3
4	In0.2Al0.367GaAs	p-	Graded Band	1.00E+17	3
5	In0.2Al0.234GaAs	p-	Graded Band	1.00E+17	3
6	In0.2Al0.100GaAs	p-	Graded Band	1.00E+17	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	[illegible]
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	p13	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+17	1000
19	InP	I-	Buffer	0.00E+00	50

p13	3.50E+17	4.00E+17	4.50E+17	5.00E+17	5.50E+17	6.00E+17	6.50E+17	7.00E+17	7.50E+17	8.00E+17
Center	1008.3	1023.1	1037.8	1052.6	1067.3	1081.9	1096.6	1111.2	1125.8	1140.4
Margin	612.1	612.2	612.05	611.97	612.1	612.2	612.12	612.16	612.12	612.2

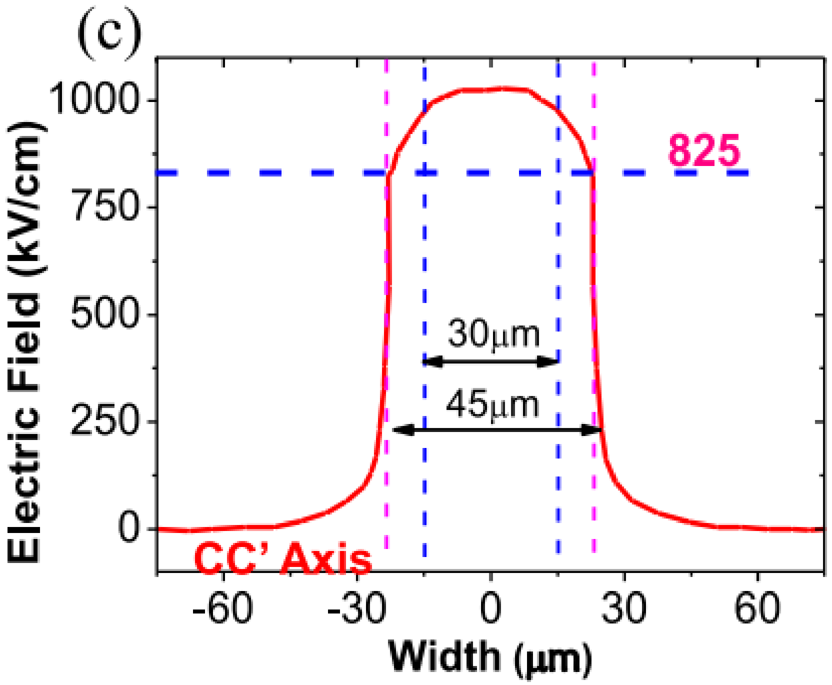


Structure B comparison

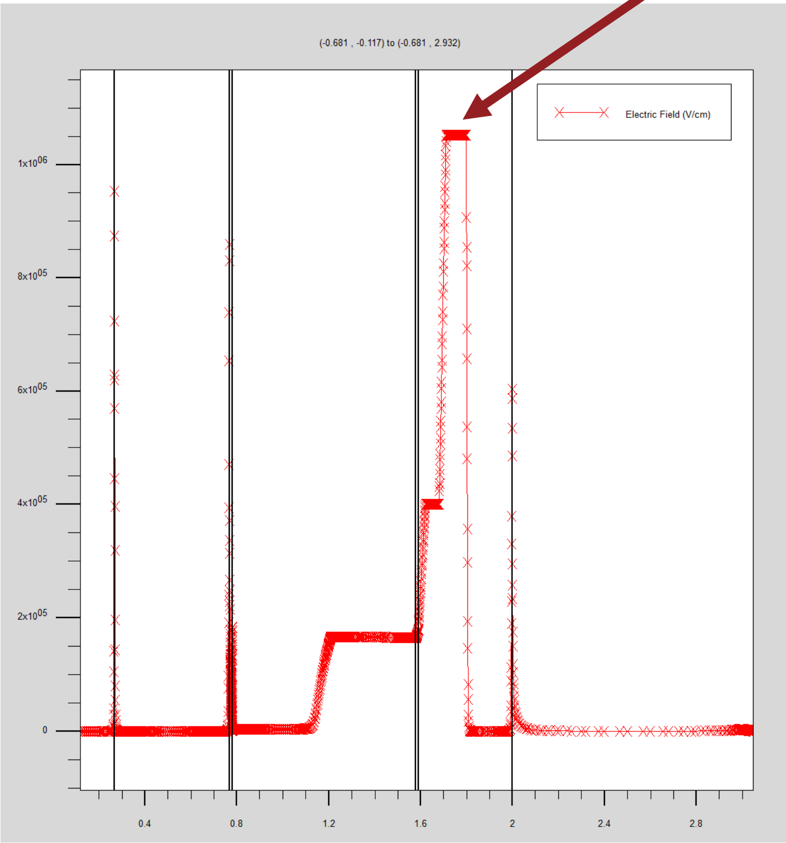
Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

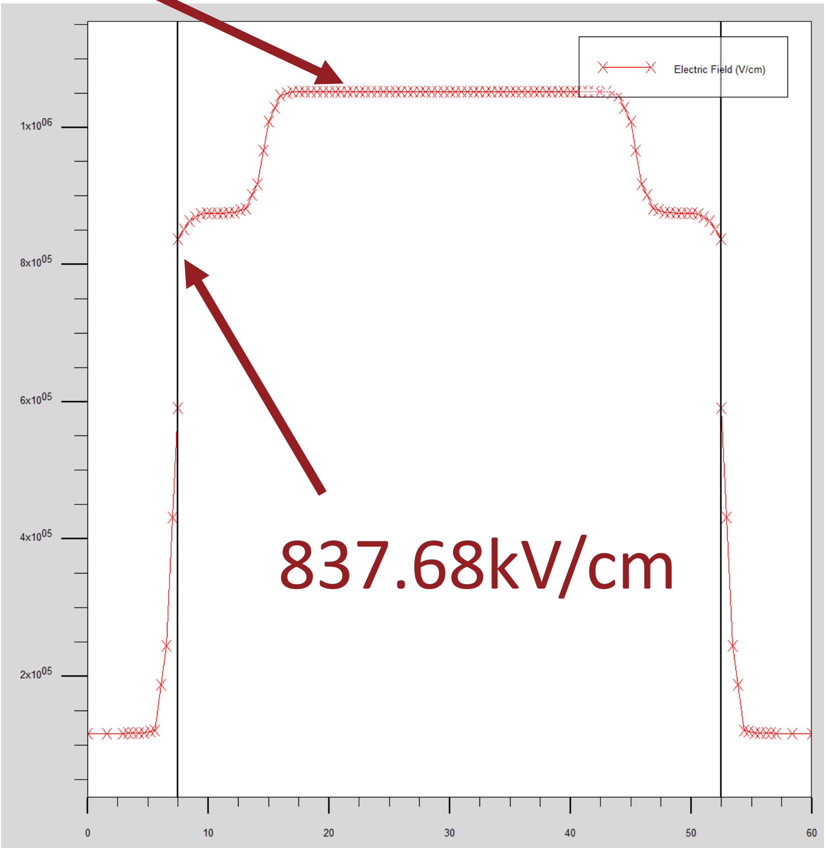
Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

Structure B comparison



1052.4kV/cm





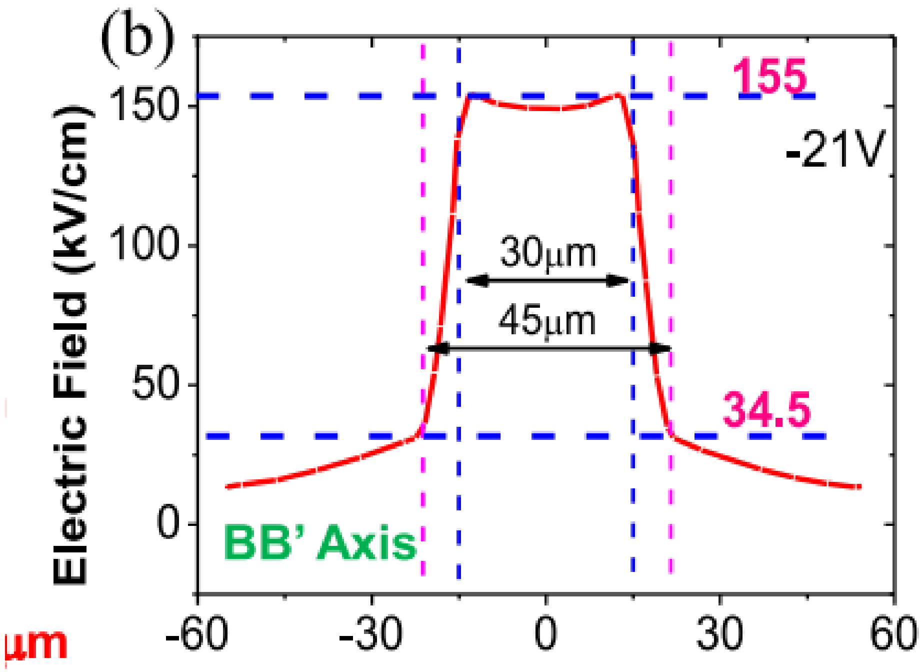
837.68kV/cm

Structure C comparison

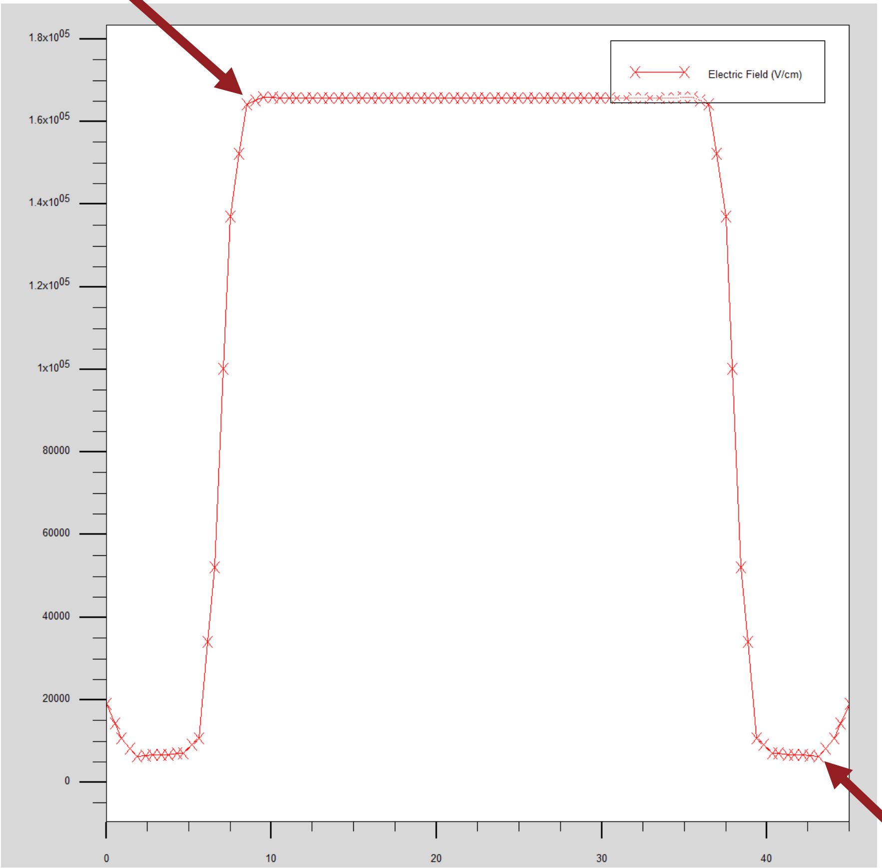
Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	2.00E+19	150
2	InP	p+	Contact	2.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	6.00E+16	3
4	In0.2Al0.367GaAs	p-	Graded Band	6.00E+16	3
5	In0.2Al0.234GaAs	p-	Graded Band	6.00E+16	3
6	In0.2Al0.100GaAs	p-	Graded Band	6.00E+16	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	0.00E+00	370
9	In0.2Al0.100GaAs	I-	Graded Band	0.00E+00	3
10	In0.2Al0.234GaAs	I-	Graded Band	0.00E+00	3
11	In0.2Al0.367GaAs	I-	Graded Band	0.00E+00	3
12	In0.2Al0.500GaAs	I-	Graded Band	0.00E+00	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	0.00E+00	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	0.00E+00	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+19	1000
19	InP	I-	Buffer	0.00E+00	50

Structure C comparison



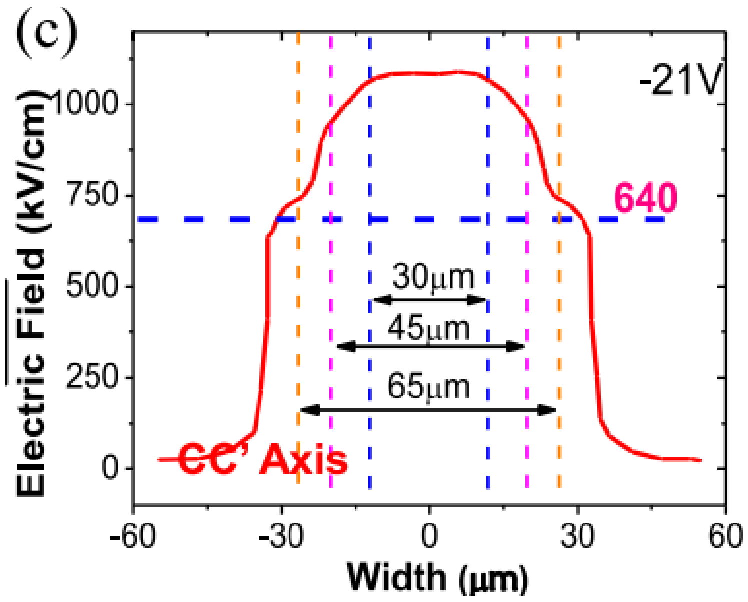
165.78kV/cm

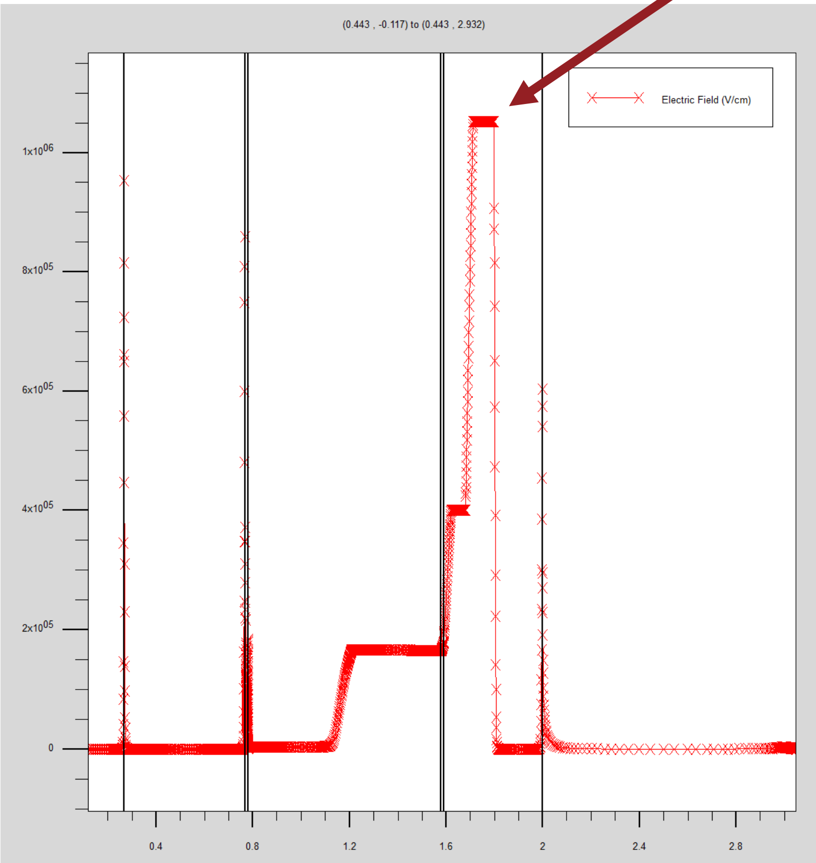


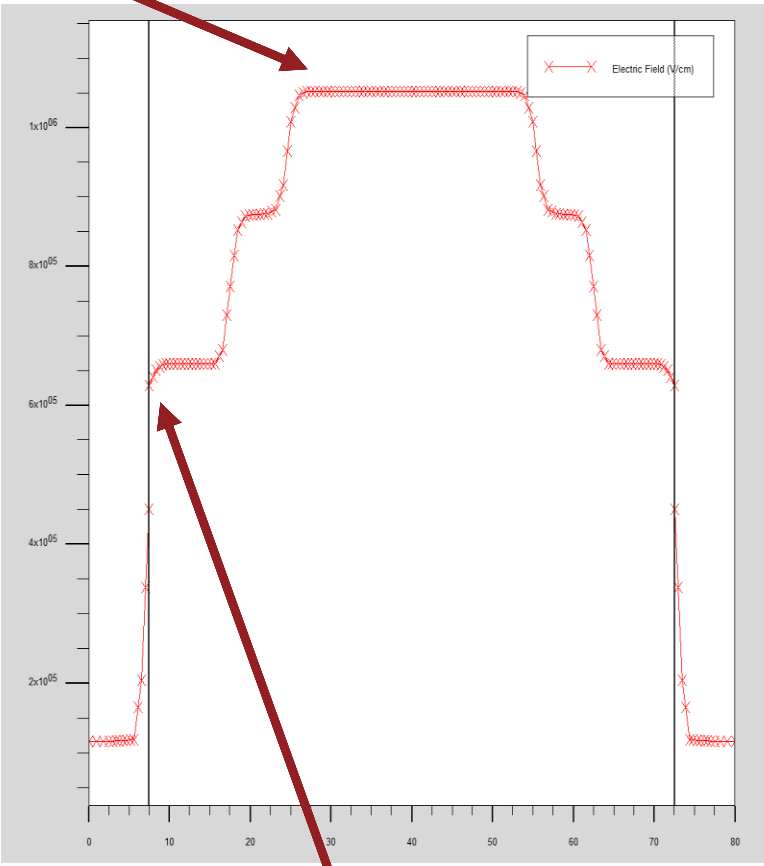
64kV/cm

Structure C comparison

1052.4kV/cm





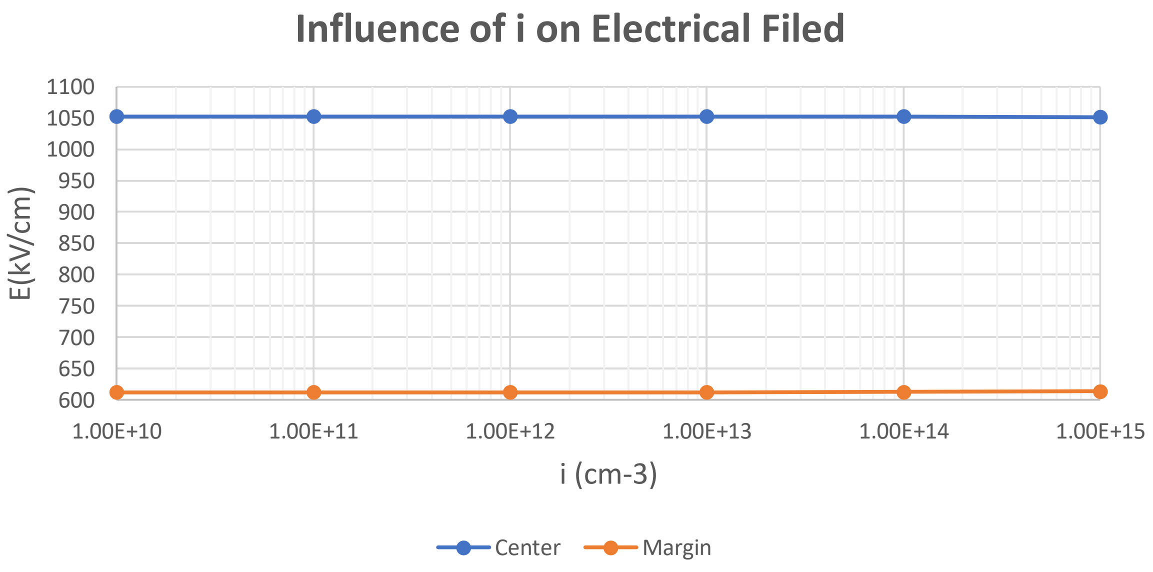


629.04kV/cm

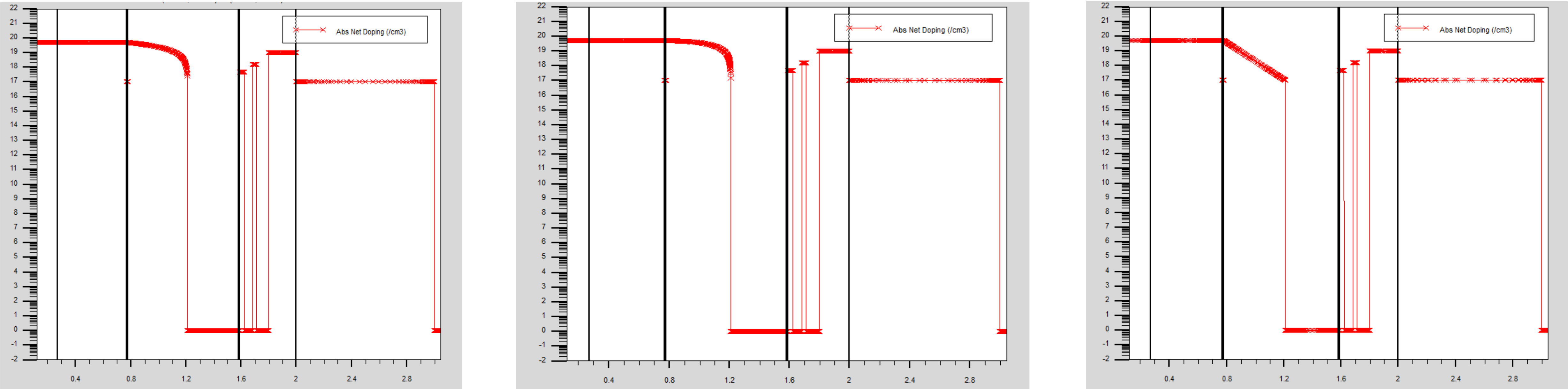
i

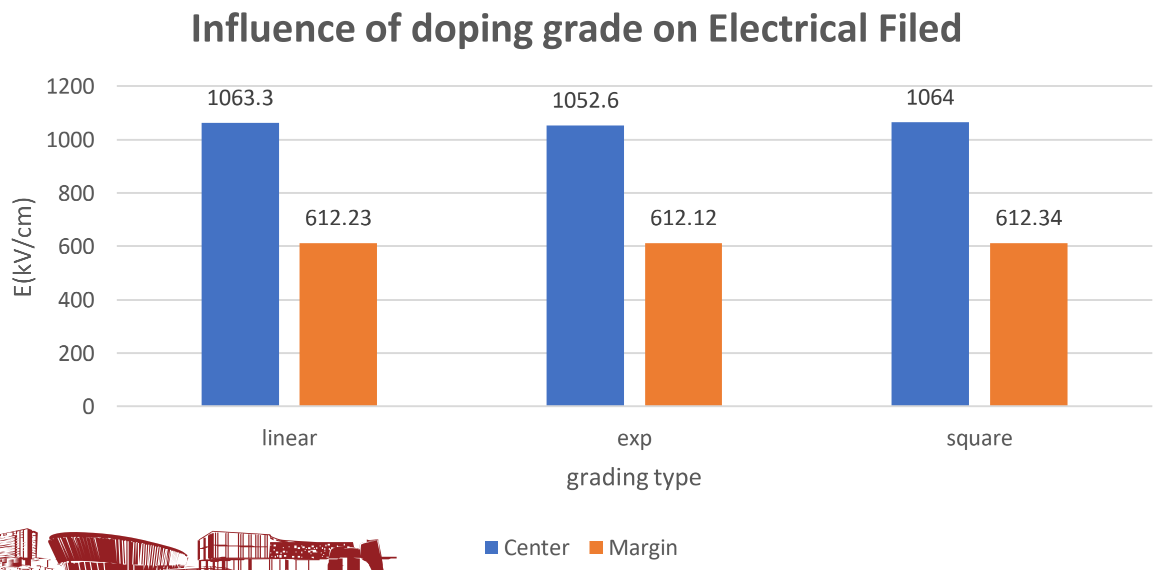
Ind	Material	Dope	Name	Conc	Depth
1	In0.53Ga0.47As	p+	Contact	5.00E+19	150
2	InP	p+	Contact	5.00E+19	500
3	In0.2Al0.500GaAs	p-	Graded Band	1.00E+17	3
4	In0.2Al0.367GaAs	p-	Graded Band	1.00E+17	3
5	In0.2Al0.234GaAs	p-	Graded Band	1.00E+17	3
6	In0.2Al0.100GaAs	p-	Graded Band	1.00E+17	3
7	In0.53Ga0.47As	p+	Graded Absorber	graded	430
8	In0.53Ga0.47As	I-	Undoped Absorber	i	370
9	In0.2Al0.100GaAs	I-	Graded Band	i	3
10	In0.2Al0.234GaAs	I-	Graded Band	i	3
11	In0.2Al0.367GaAs	I-	Graded Band	i	3
12	In0.2Al0.500GaAs	I-	Graded Band	i	3
13	In0.52Al0.48As	p-	Charge	5.00E+17	30
14	In0.52Al0.48As	I-	Field Buffer	i	60
15	In0.52Al0.48As	p+	Charge	1.50E+18	30
16	In0.52Al0.48As	I-	Multiplication	i	88
17	In0.52Al0.48As	n-	Contact	1.00E+19	200
18	InP	n-	Contact	1.00E+17	1000
19	InP	I-	Buffer	i	50

i	1.00E+10	1.00E+11	1.00E+12	1.00E+13	1.00E+14	1.00E+15
Center	1052.6	1052.6	1052.6	1052.6	1052.6	1051.8
Margin	612.16	612.11	612.26	612.22	612.56	613.72



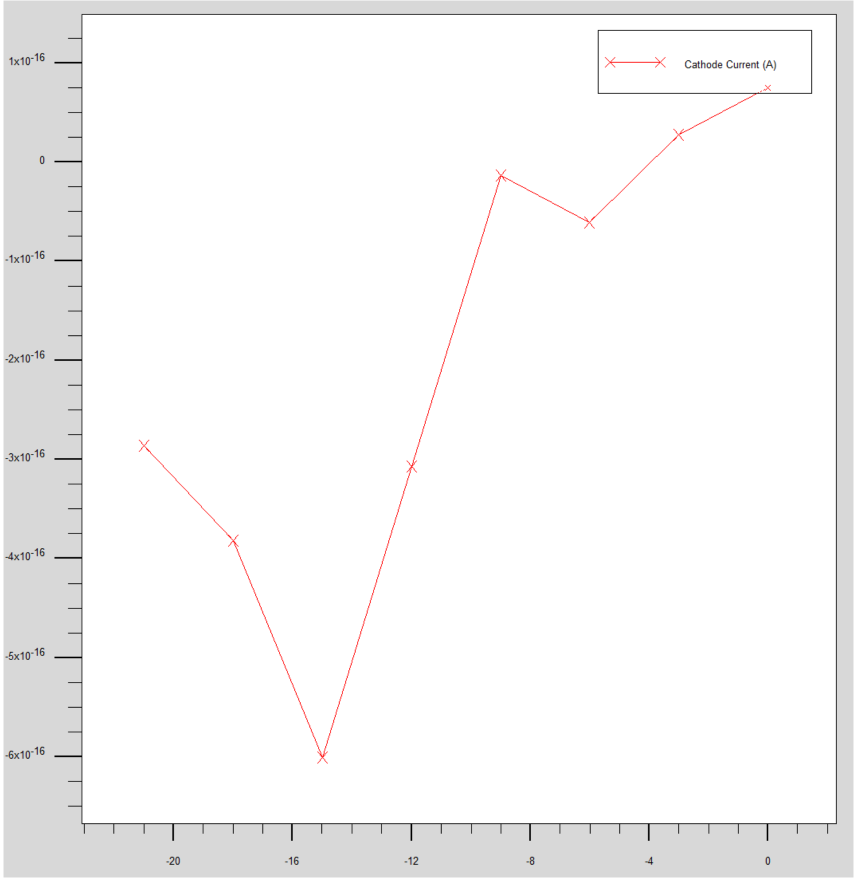
Graded doping type



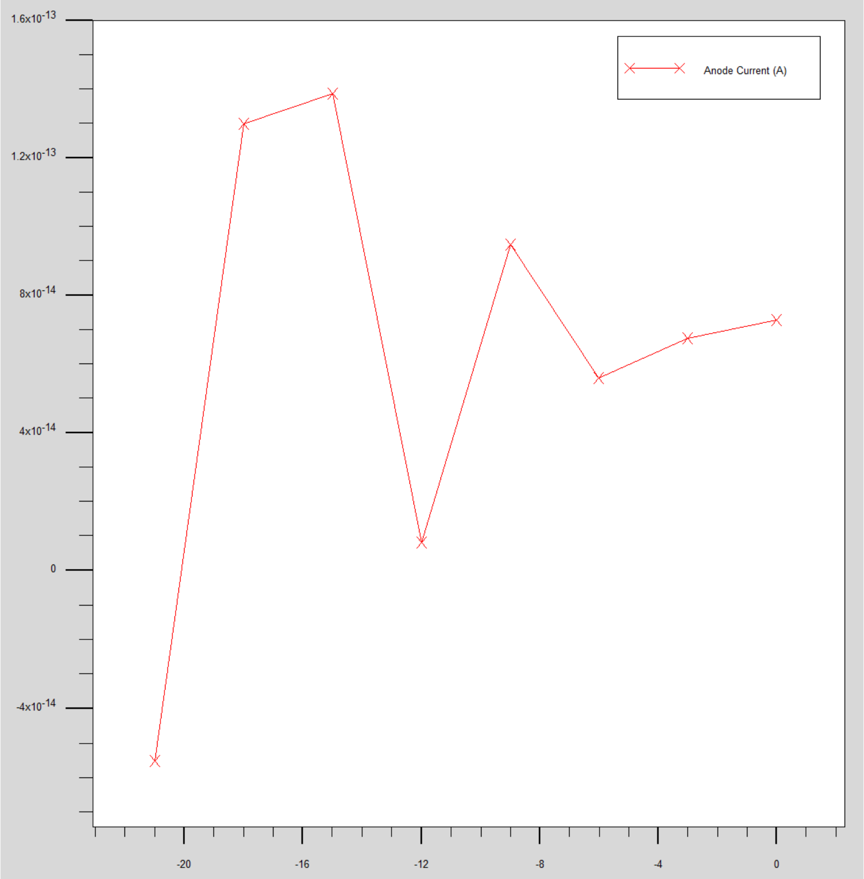


$$J_{p,diff} = eD_p \frac{dp}{dx}$$

Current



Dark Current



Light Current