Characterization and Optimization of High Power InGaAs/InP Photodiodes

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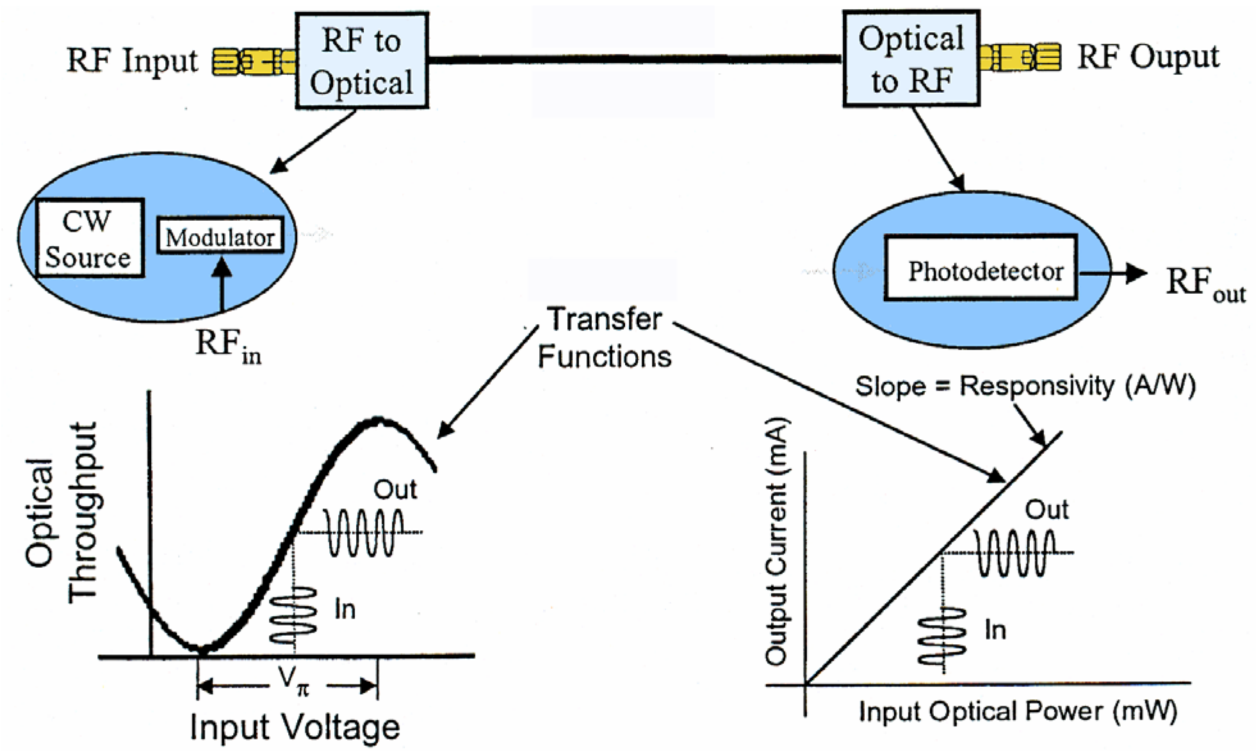
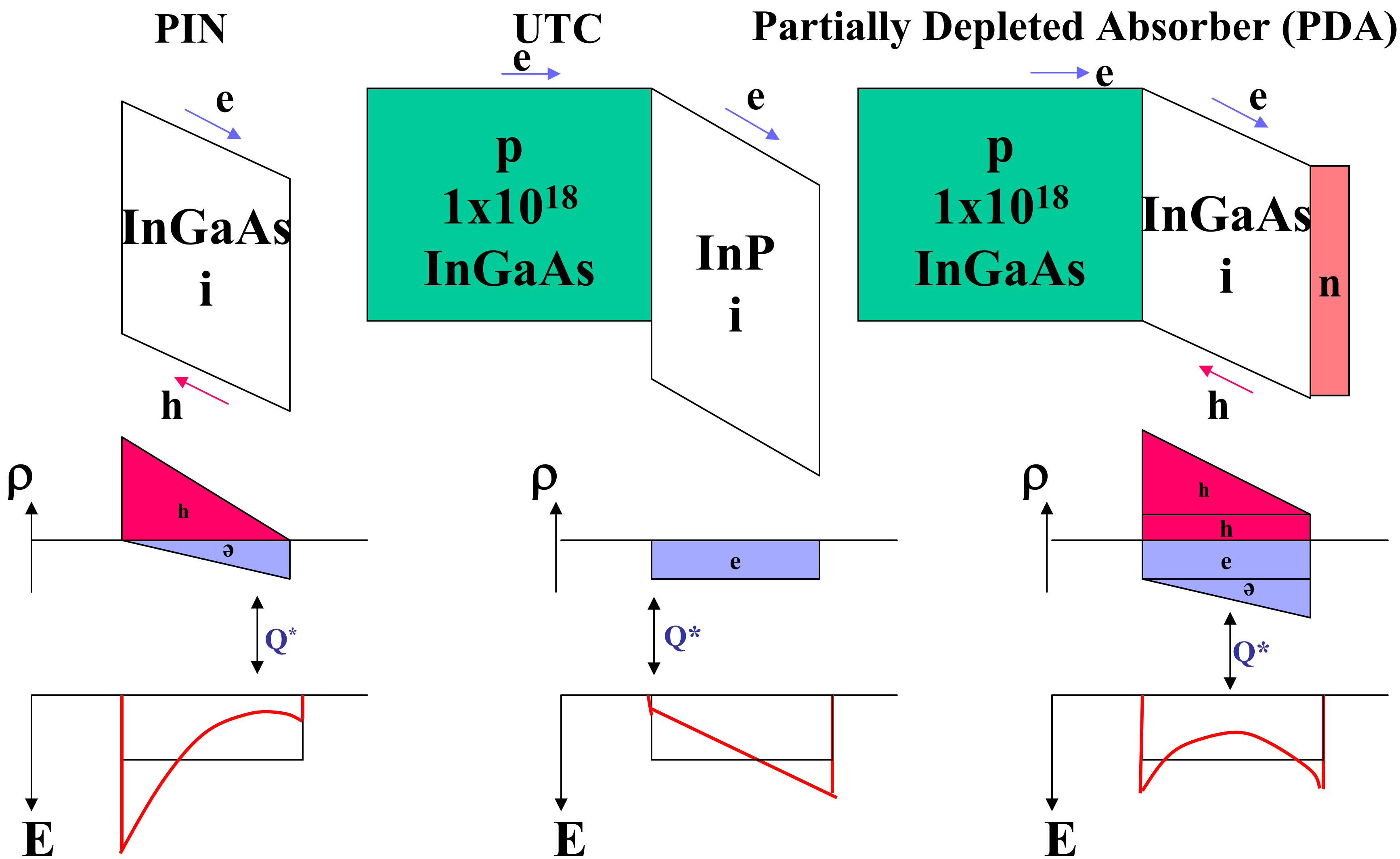
Analog Fiber Optic Links



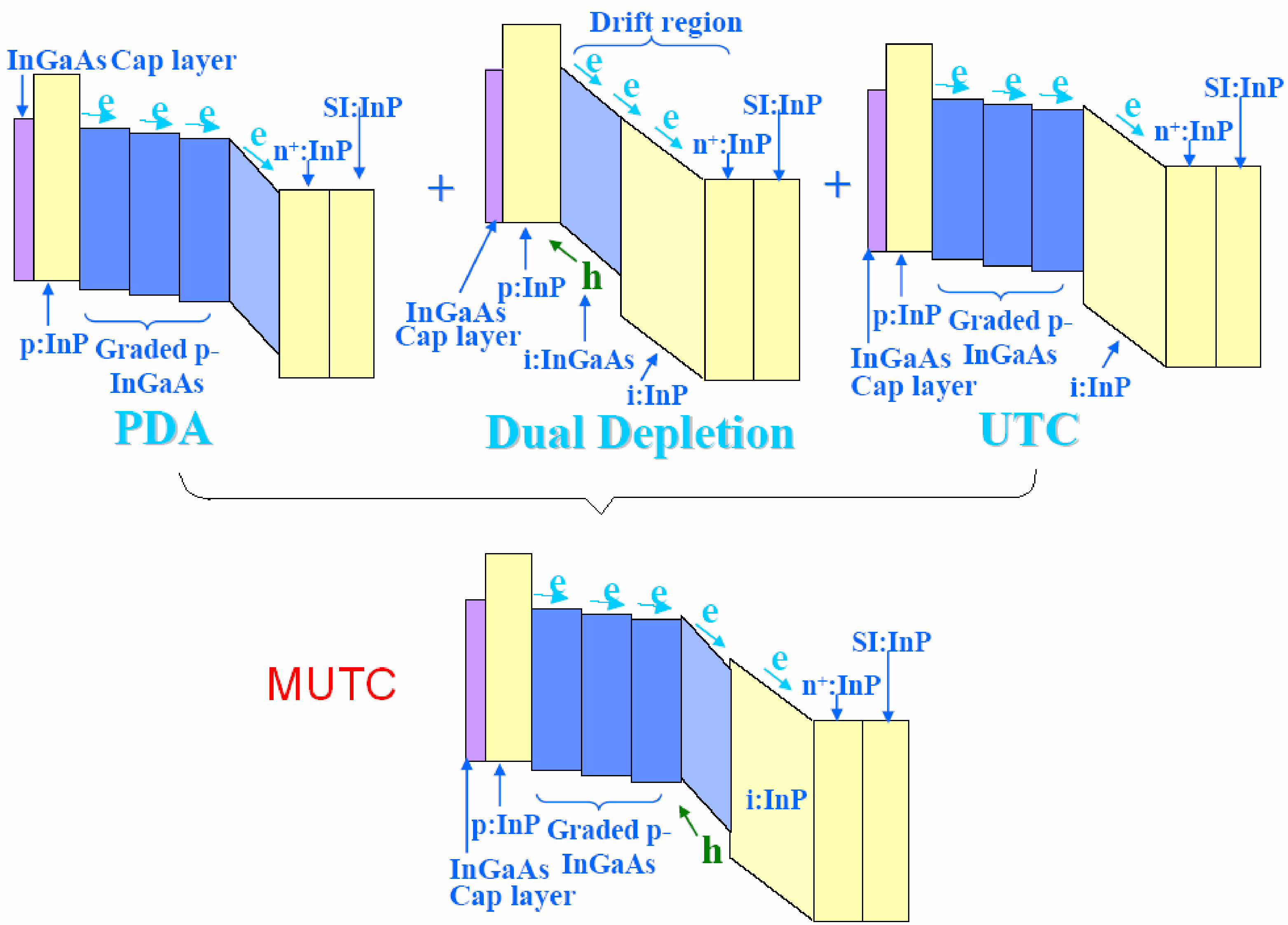
I_{photo} ↑ ⇒ Gain ↑ Noise ↓ Spur free dynamic range ↑

Schematic Representations of Charge Distribution



*Q: where the E-field collapses first.

Evolution of the Epi-structures



High Power Photodiode with Modified UTC Structure

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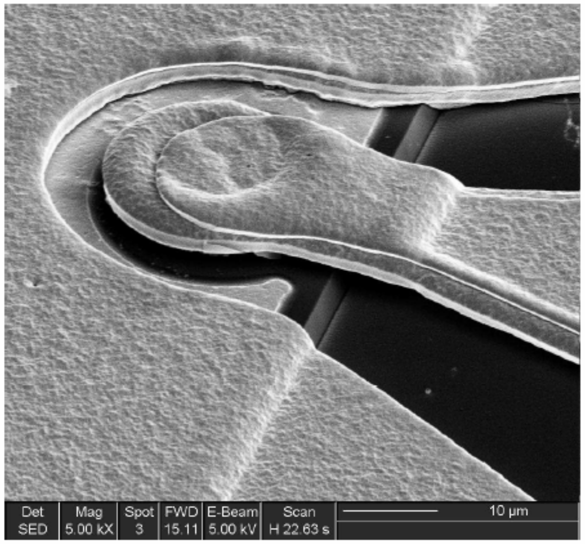
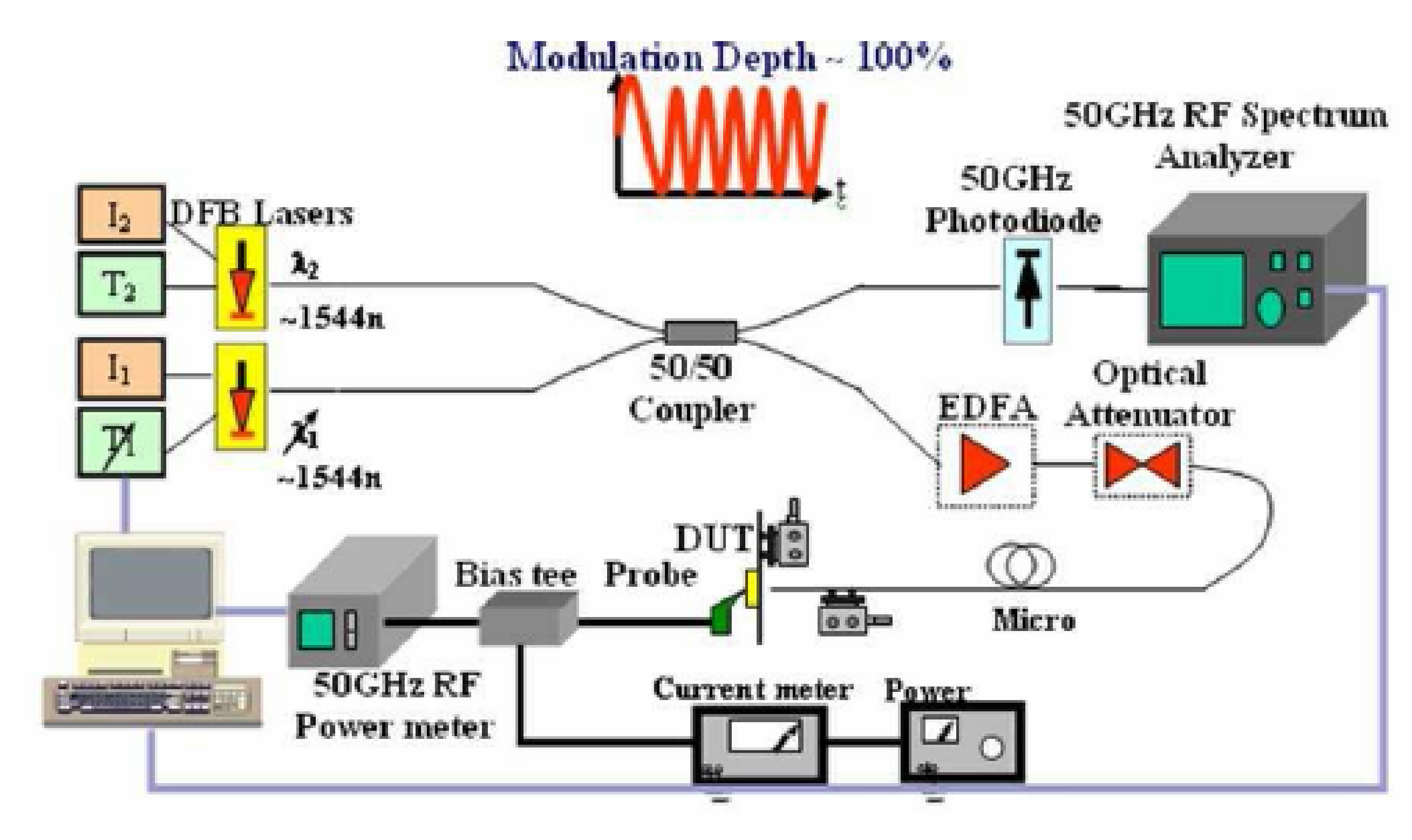


Diameter=34µm
Series resistance=5.6 Ω
Load resistance=50 Ω
Capacitance=166fF
Saturation Current = 100mA @ -5V
Responsivity=0.75A/W
Bandwidth =17GHz

InGaAs, p^+ , Zn, 2.0x10^{19}, 50nm	
InP, p+ , Zn, 3x10^{18}, 1000nm	
InGaAs, Zn, 2x10^{18}, 100nm	Graded-doped p-absorber
InGaAs, Zn, 1x10^{18}, 150nm	
InGaAs, Zn, 5x10^{17}, 200nm	
InGaAs, Zn, 2.5x10^{17}, 200nm	
InGaAs, Si, 1.0x10^{16}, 200nm	Intrinsic absorber
InGaAsP,Q1.4, undoped, 15nm	Graded layer
InGaAsP,Q1.1, undoped, 15nm	
InP, Si, 1.0x10^{16}, 605nm	Intrinsic collector
InP, n+, Si, 1.0x10^{19}, 1000nm	
InGaAs, n+, Si, 1.0x10^{19}, 20nm	
InP, n+, Si, 1.0x10^{19}, 200nm	
InP, semi-insulating substrate, Double side polished	

Back-illuminated

Measurement Setup



Simulation Tools and Saturation Machnisms

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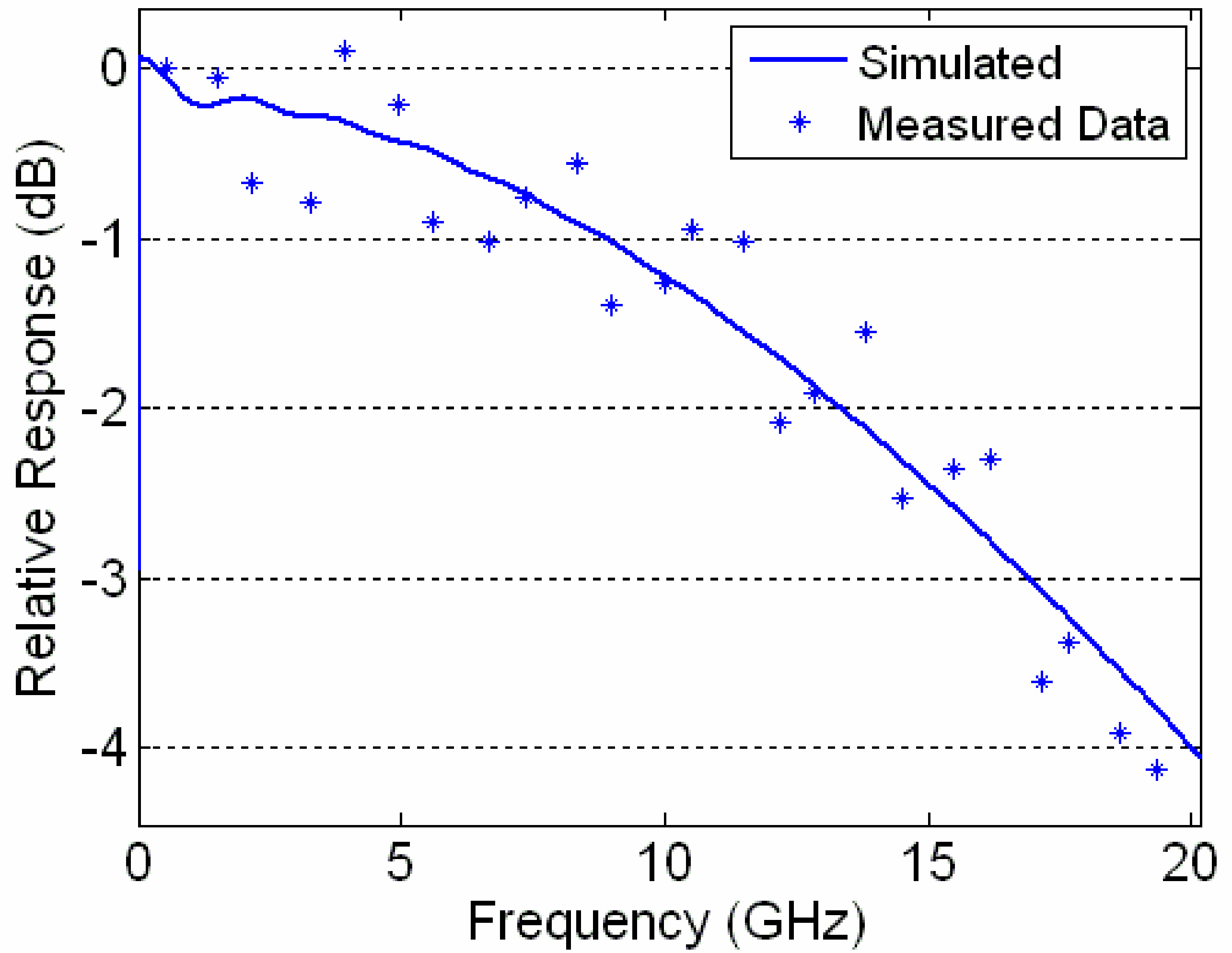
CROSSLIGHT Software Inc. Crosslight Software Inc

Mechanism	**Included in Present 2-D Model**
Space-Charge Electric Fields	Yes
Field Dependent Mobilities	Yes
Generation in Undepleted Regions	Yes
Diffusion	Yes
Trapping	Yes
Heterojunctions	Yes
Thermal Effect	Yes
Loading in the External Circuit	Partial
Transient Temperature Rise	No
Carrier Bleaching	No

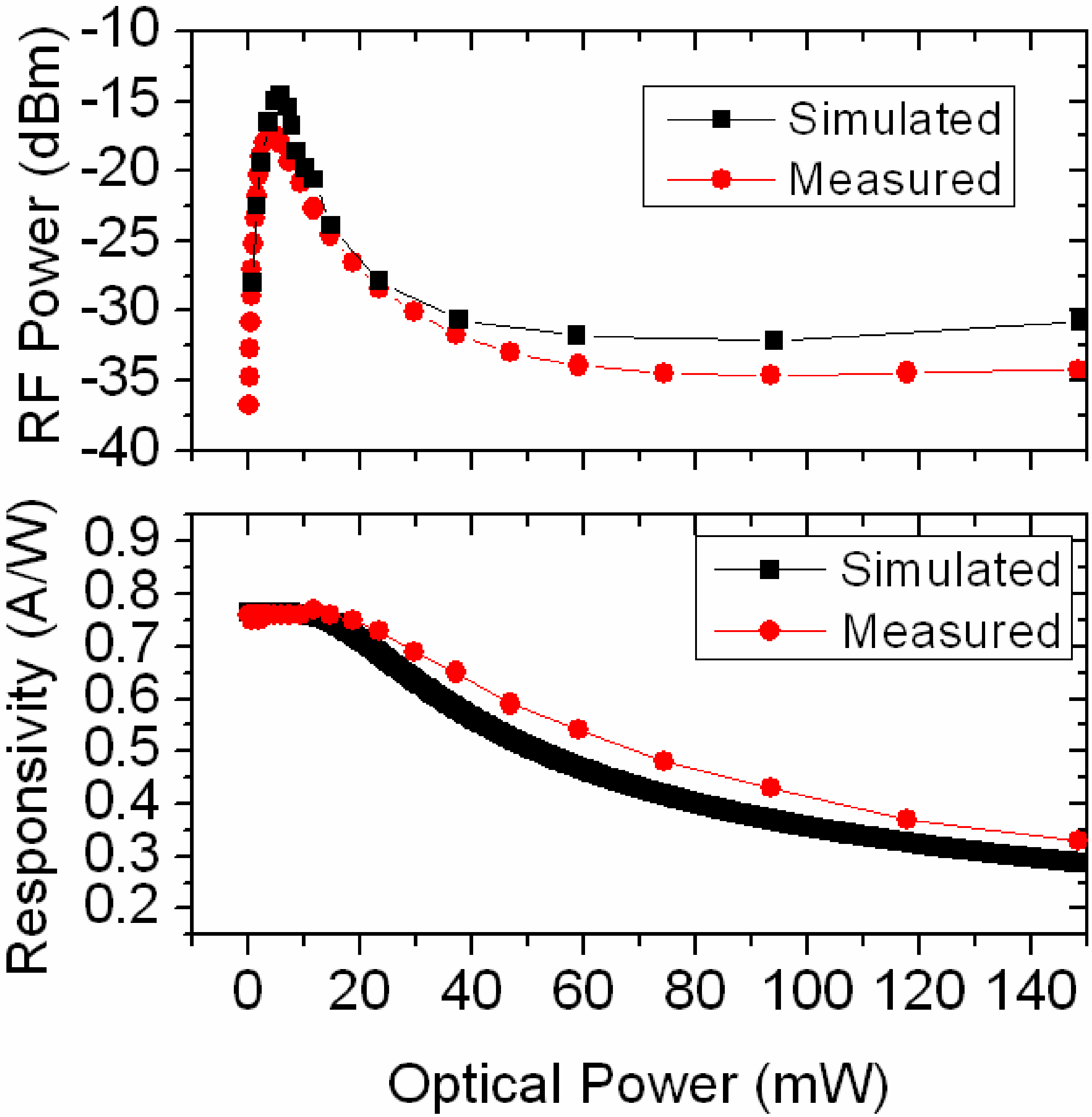
Bandwidth of the Photodiode



Frequency response measure at -5V, 30mA.

RC-limited bandwidth f_{RC} = 17GHz

Saturation Behavior of the Photodiode



Experiment Condition:

Zero bias

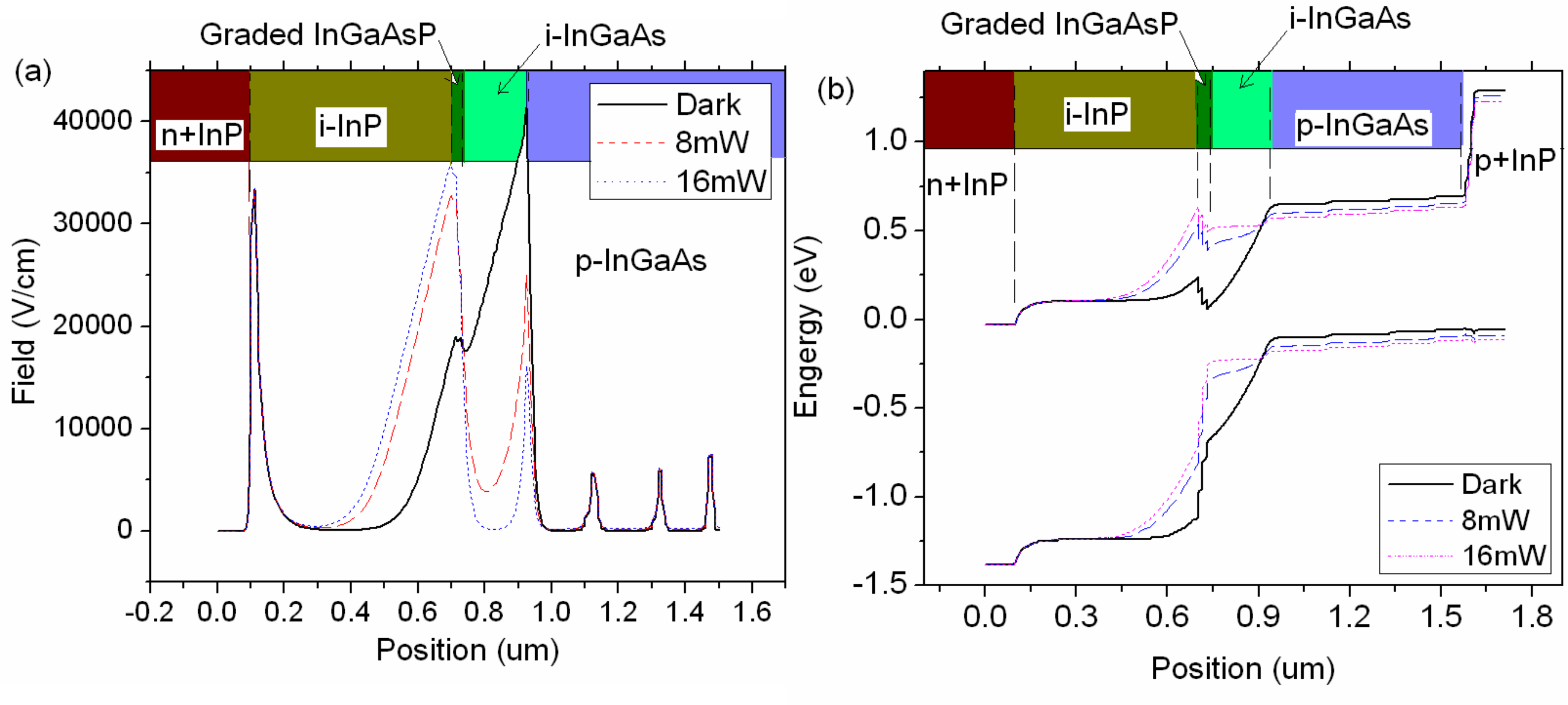
Simulation Includes:

5.6 Ω series resistance

Thermal effect

50 Ω load resistance not included

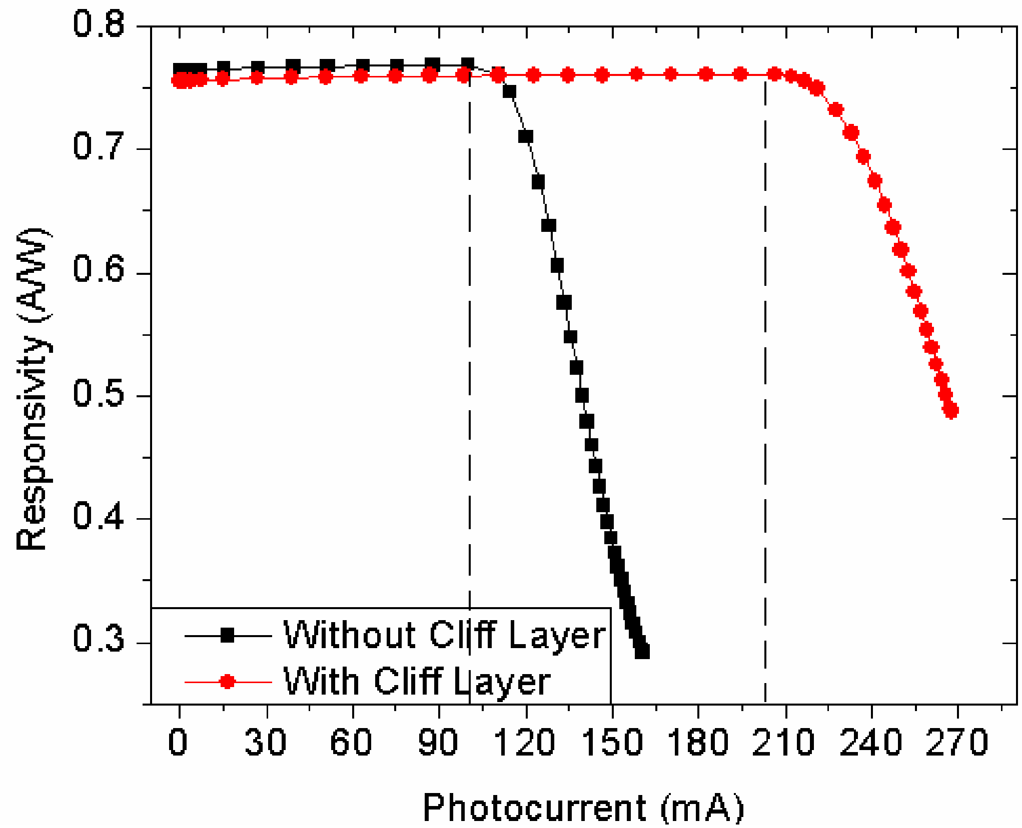
Saturation



Electric field in the i-InGaAs reduced, band discontinuity becomes more pronounced

Reduced Saturation Effect with Cliff Layer

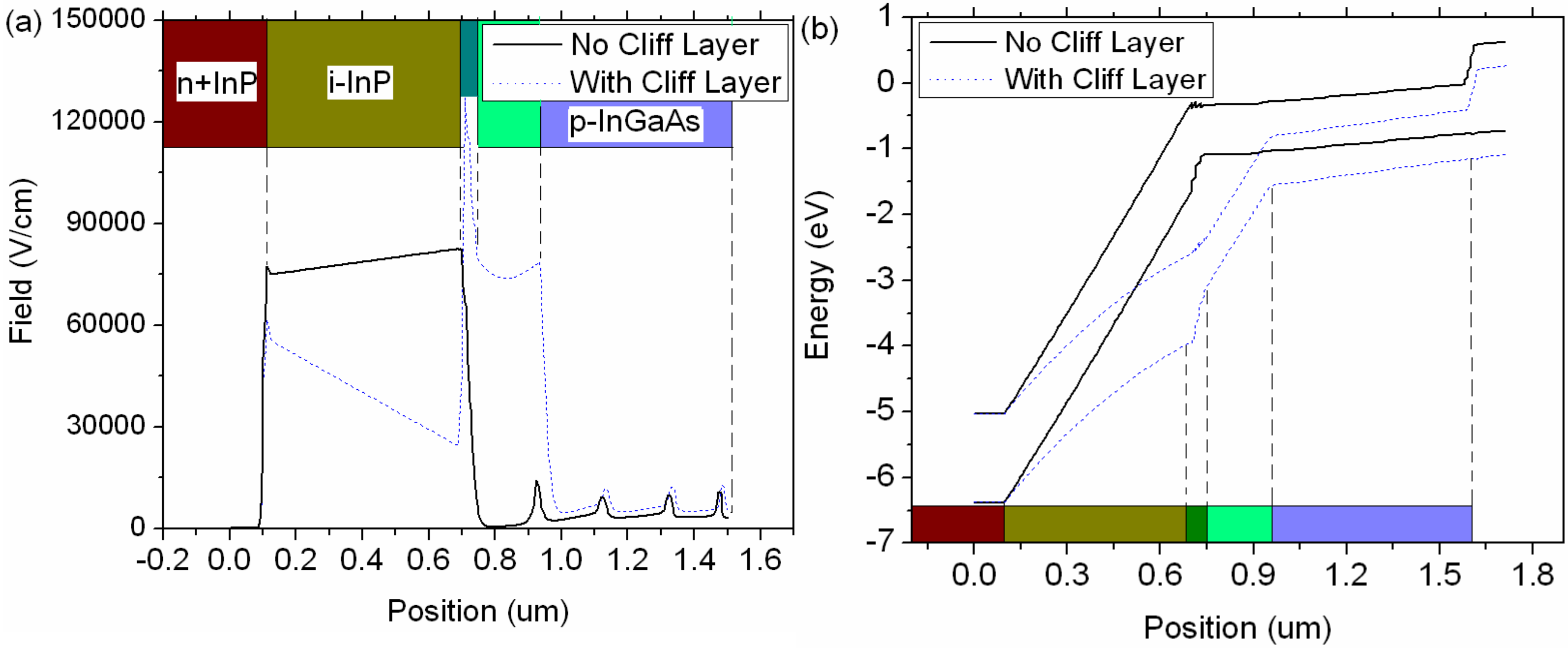
InGaAs, p^+, Zn, 2.0×10^{19}, 50nm
InP, p+, Zn, 1.8×10^{18}, 1000nm
InGaAs, Zn, 2×10^{18}, 100nm
InGaAs, Zn, 1×10^{18}, 150nm
InGaAs, Zn, 5×10^{17}, 200nm
InGaAs, Zn, 2.5×10^{17}, 200nm
InGaAs, Si, 1.0×10^{16}, 200nm
InGaAsP, undoped, Q1.4, 15nm
InGaAsP, undoped, Q1.1, 15nm
InP, Si, 5×10^{17}, 5nm
InP, Si, 1.0×10^{16}, 600nm
InP, n+, Si, 1.0×10^{19}, 1000nm
InGaAs, n+, Si, 1.0×10^{19}, 20nm
InP, n+, Si, 1.0×10^{19}, 200nm
InP, semi-insulating substrate, Double side polished



Condition: -5V, T=300K

Moderately doped cliff layer

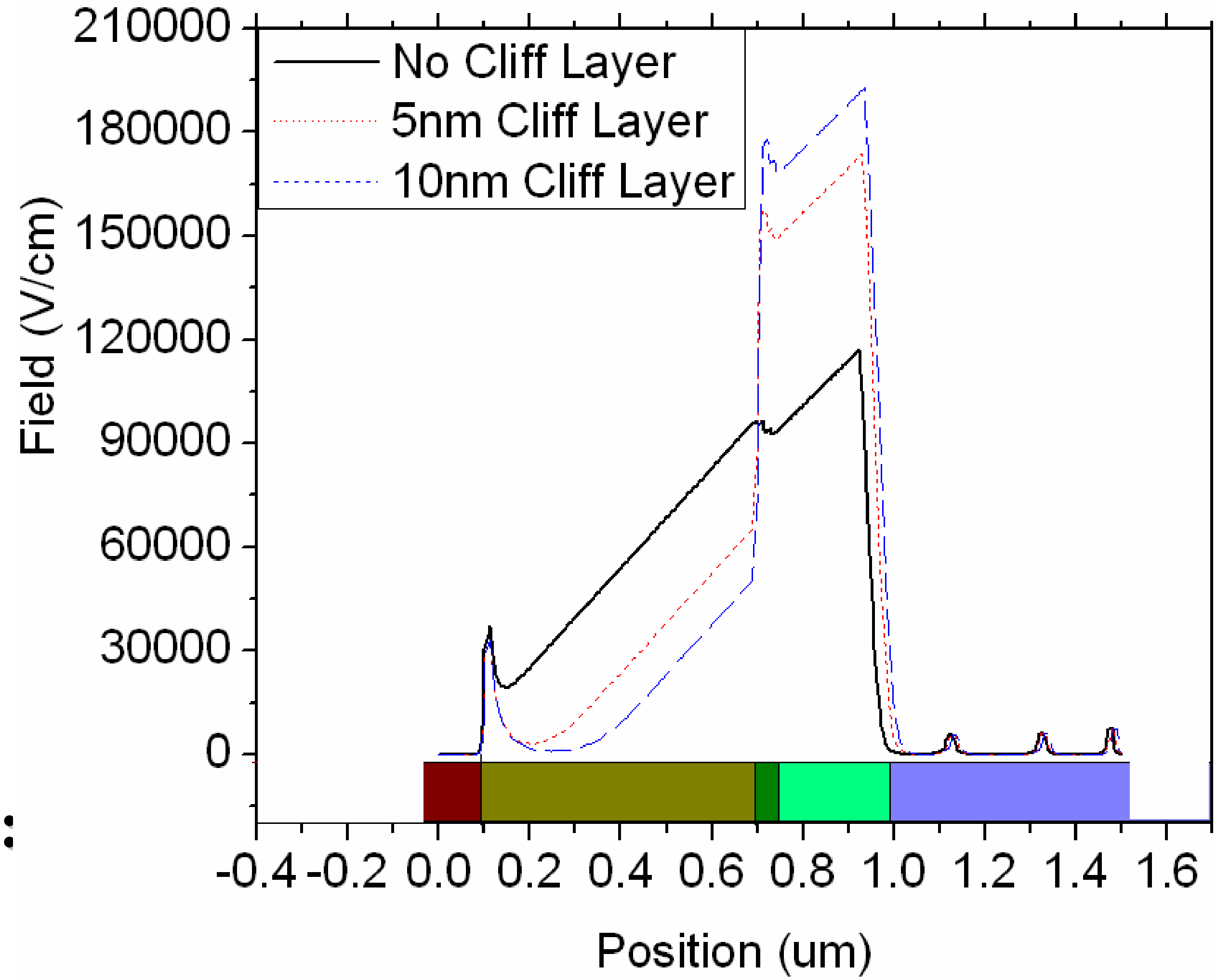
Role of the Cliff Layer



Condition: -5V, Optical power 235mW

Electric field enhanced in i-InGaAs absorber.
Effect of band discontinuity reduced

Optimization of the Cliff Layer



Optimized cliff layer:

Thickness: 5nm

Doping: 5×10^{17} cm^{-3}, n-type

Optimization of the Intrinsic Absorber and Collector

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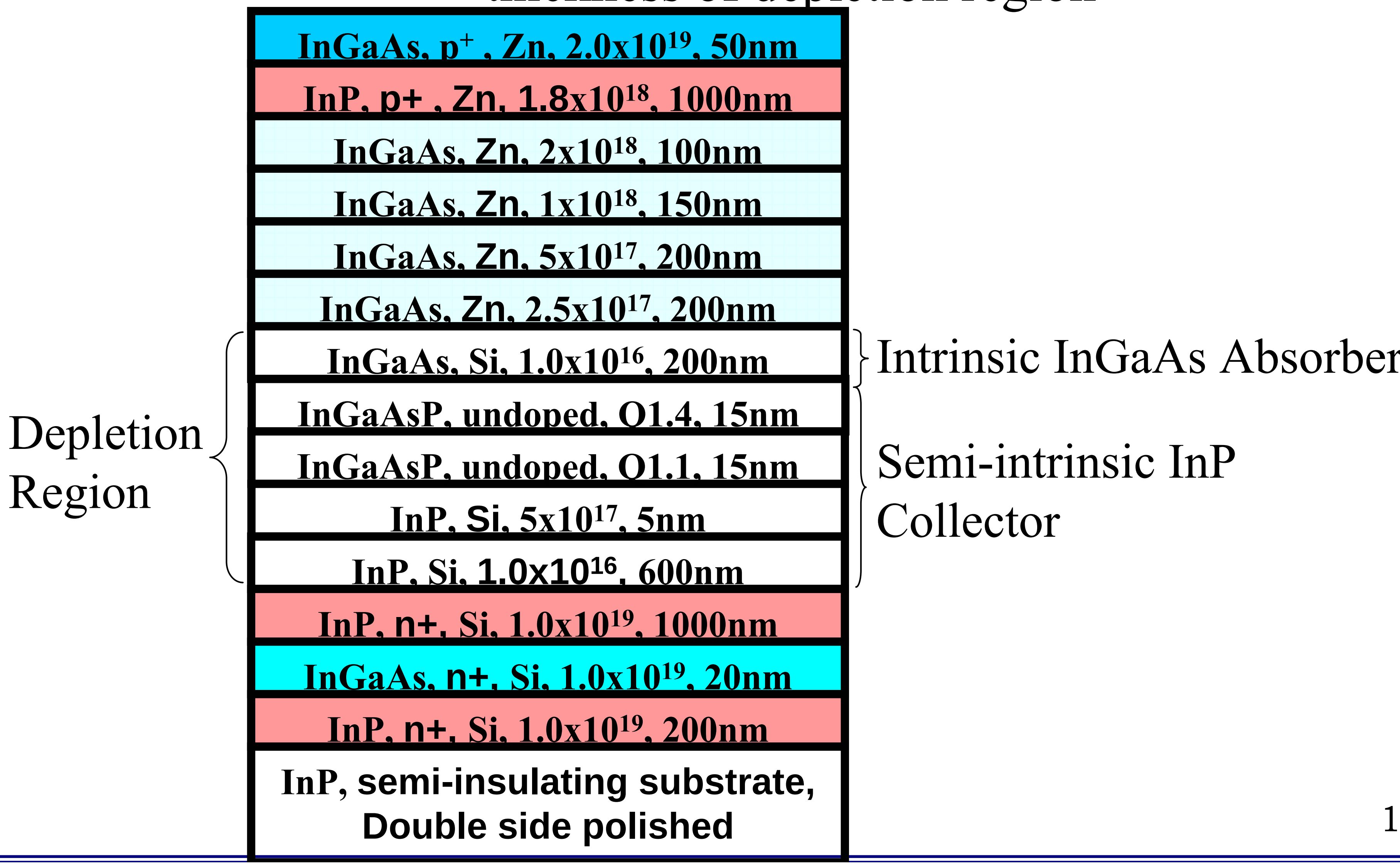
$$Fraction = \frac{\text{thickness of i-InGaAs}}{\text{thickness of depletion region}}$$



Optimization of the Intrinsic Absorber and Collector

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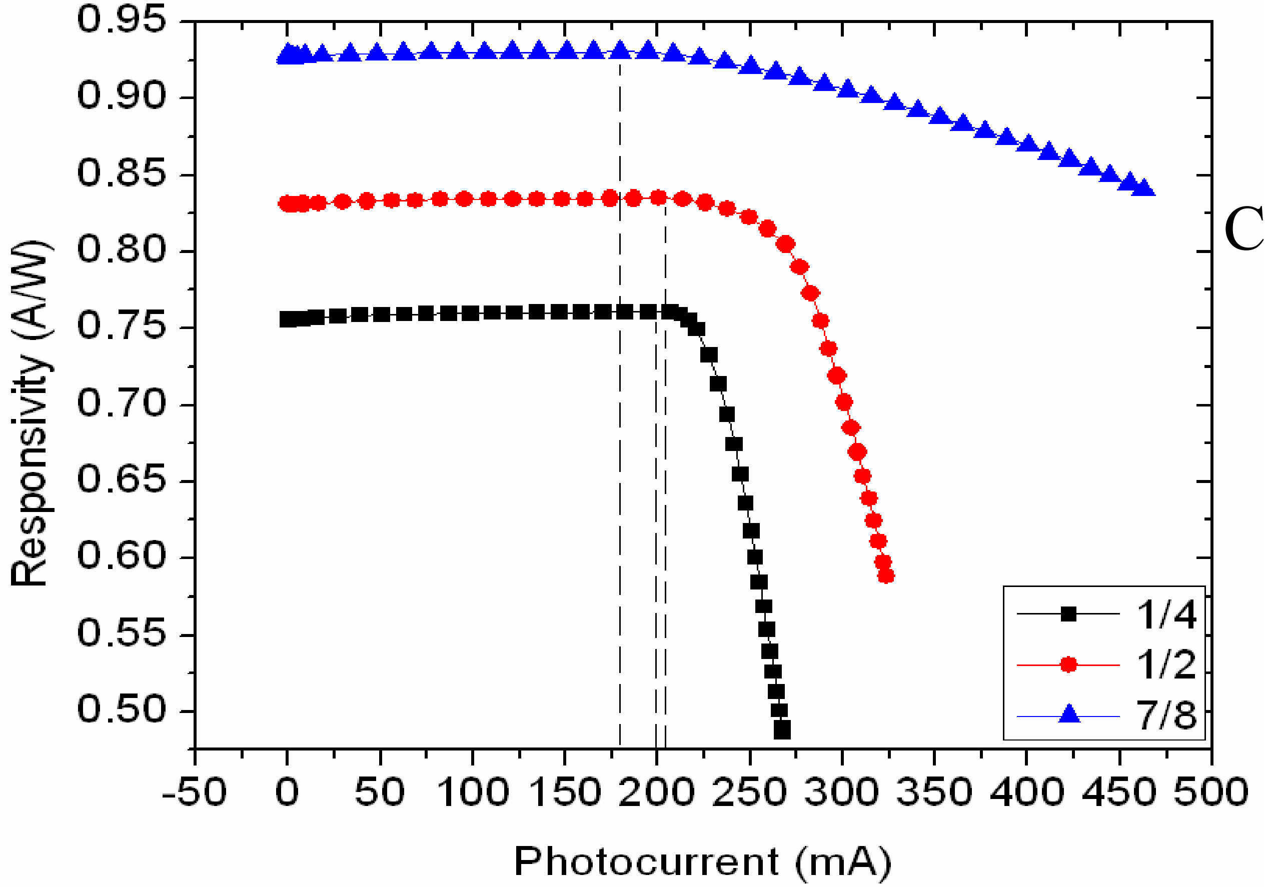

Conditions:

Bias: -5V

Temperature: 300K

Degradation current: photocurrent at maximum responsivity

Maximum when i-InGaAs = ½ depletion region

Summary

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- Bandwidth of our high power photodiode is RC-limited.
- Saturation effect - electric field screening and band discontinuity at the interface of i-InGaAs and i-InP
- A cliff layer can be introduced to reduce space charge effect – 2x degradation current
- Optimum i-InGaAs fraction = 50% in MUTC structure