Semiconductor Optical Communication Components and Devices

Lecture 35: Other High Speed Photodiodes

Prof. Utpal Das

Professor, Department of Electrical Engineering, Laser Technology Program, Indian Institute of Technology, Kanpur

http://www.iitk.ac.in/ee/faculty/det_resume/utpal.html
Overcome Limitations of Speed & Efficiency

Resonant-cavity-enhanced photodetector (RCE-PD)

- Input Light
- Front reflector
- Back reflector
- Photo absorption layer

Graph:
- Frequency (GHz) vs. Photo-absorption layer thickness (μm)
- VPD
- RFPD (θ=30°)
- RFPD (θ=54°44′/″)

Efficiency

- Overcome Limitations of Speed & Efficiency
- Resonant-cavity-enhanced photodetector (RCE-PD)
Vertical Photodiode & Waveguide Photodiode

20x25mm 10GHz Vertical photodiode with p- and n-contacts (far top) on the same side.

SI Substrate
Travelling Wave Photodetector
Absorption Layer Thickness

- Frequency (GHz)
- Photo-absorption Layer Thickness (µm)
- Optical wave Velocity
  - 8.6x10^9 cm/s
- Electrical wave Velocity (10^9 cm/s)

- w=2µm η=70%
- w=1µm η=49%
- w=0.5µm η=24%
Waveguide Avalanche Photodiode

50 nm InGaAs
200 nm InAlAs
100 nm InAlGaAs
‘A’ 200 nm InGaAs
100 nm InAlGaAs
‘C’ 180 nm InAlAs
‘M’ 150 nm InAlAs
300 nm InAlAs
100 nm InP

Bandwidth (GHz)
Gain
Gain-Bandwidth=320GHz

3-dB bandwidth of 28GHz up to a gain of six
Periodically Intermixed Absorption Region Of TWPD

Guided Optical Wave

F Implant

F Implant

F Implant

n InP Buffer Layer

Substrate

Substrate

InGaAs Contact Layer

Top InGaAsP Cladding Layer

Bottom InGaAsP Cladding Layer

n InP

p InP

λ_1

λ_2

λ_3

i MQW

n InP Buffer Layer

n^+ InP Buffer Layer
Velocity Matched Waveguide Photodiode

Optical Waveguide

Waveguide Photodiode

Coplanar RF Ground Plane

Coplanar RF waveguide

Periodic Waveguide Photodiodes

Velocity Matched RF Line
Periodically intermixed absorption region of TWPD

Intrinsic MQW Layer

N bottom Cladding Layer

N+ Contact Layer

P+ Contact Layer

P top Cladding Layer

Guided Optical Wave

N+ Substrate

F implant

Glassy Implant Mask

Absorbing Regions OR gap Regions, as designed

N+ Substrate
Periodic Unitraveling Carrier Waveguide Photodiode

\[ f_{3dB} = 115 \text{ GHz at } \lambda=1.55\mu\text{m for Periodic-TW-UTC-PD} \]

With a terminal resistor located at the input end.

Photo-response of Periodic-TW-UTC-PD is 3 times that of a single UTC-PD.

The value of \( f_{3dB} \) is almost the same as that observed in a single UTC-PD.

P-TW-UTC-PD with no terminal resistor, \( f_{3dB}=56\text{GHz} \)

Reflection of backward-propagating \( \mu \text{waves at the input end.} \)

Single quantum well detectors can go to 80GHz but efficiency would go down.
Photodiode Amplifier Bandwidth Enhancement Mechanisms:

a) Distributed Amplifier with periodic detector.

b) Velocity Matched Periodic Detector.

c) Pseudomorphic HEMT Amplifier (0.25μm gate will enable 40Gbits/s)

d) Spiral Inductor for delay and choke to extend the bandwidth.
1. Why does one expect to have enhanced responsivity in a RCE-PD even though the absorption region could be quite thin for high speed operation?

2. How is the transit time limitation overcome without compromising on the absorption length in a RFPD? What are the disadvantages of this detector?

3. What are the limitations of a waveguide photodiode, although speed may be enhanced substantially?

4. Why is it essential to match the velocity of the RF generated from the photo-response with the optical velocity in the waveguide?

5. How does waveguide photodiodes enable on-chip integration and for that matter also makes it possible to have a periodic photodiode structure? (Check last lecture on integration)