# Chapter 7. Light Detector

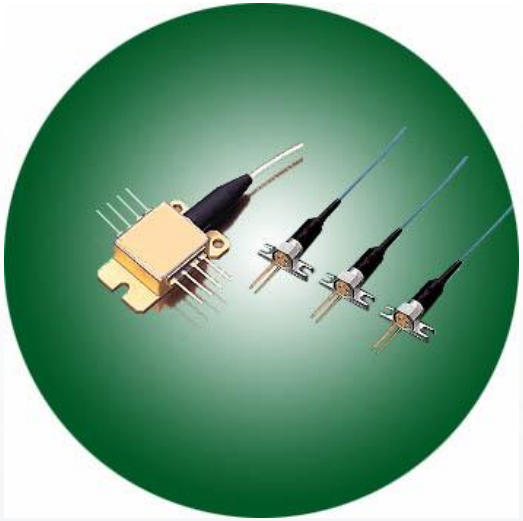


## ■ 광 검출기

- 광 신호를 전기적 신호로 변환함
- 광통신 시스템의 수신부에 설치

## ■ 광통신용 주요 광 검출기

- **PIN (Positive-Intrinsic-Negative)**
- **APD (Avalanche-Photodiode )**

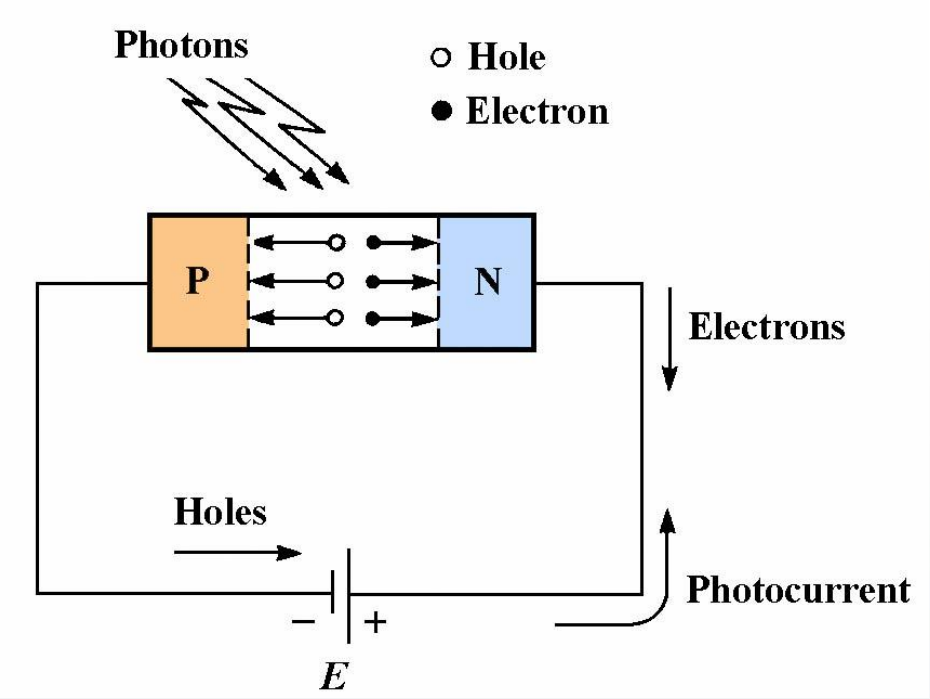


# 7-1 Principles of Photodetection

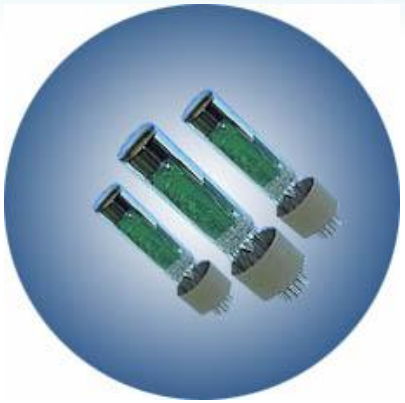
반도체 접합에서 빛 에너지를 받아
자유전자와 정공이 생성되어 전류가 발생함

## ■ 응답도 (Responsivity)

$$\rho = \frac{i}{P} \quad [\mathrm{A/W}] \qquad (7\text{-}1)$$



# 7-2 PHOTOMULTIPLIER



## ■ 전자방출조건

$$hf \geq \phi \qquad (7-3)$$

$\phi =$ Work function

## ■ 차단파장

$$\lambda_c(\mu m) = \frac{1.24}{\phi(eV)} \qquad (7-4)$$

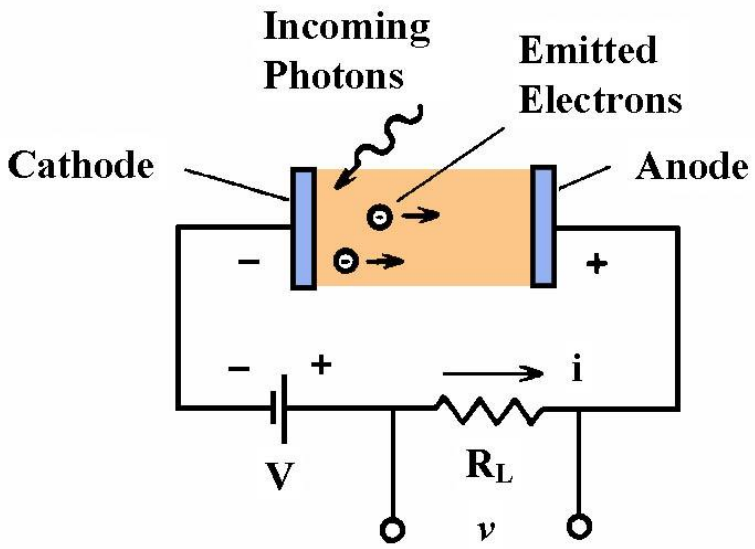


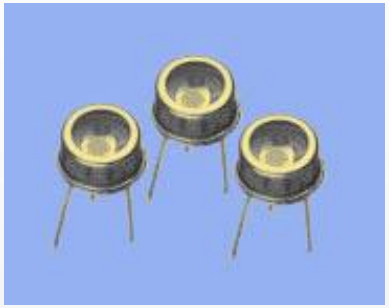

Figure 7-2 Vacuum photodiode

# 7-3 SEMICONDUCTOR PHOTODIODE

## ■ 동작원리

1. 입사광을 흡수하여
   전자와 정공이 생성됨.

2. 공핍층의 전계에 의하여
   전자와 정공이 이동함.
   (Drift 전류가 발생함.)



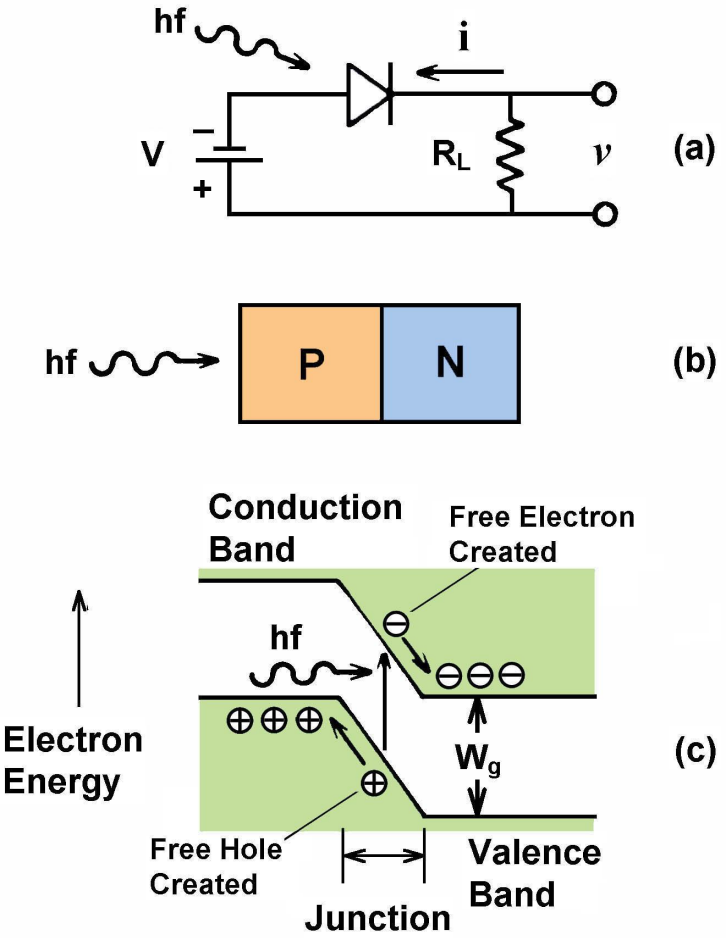
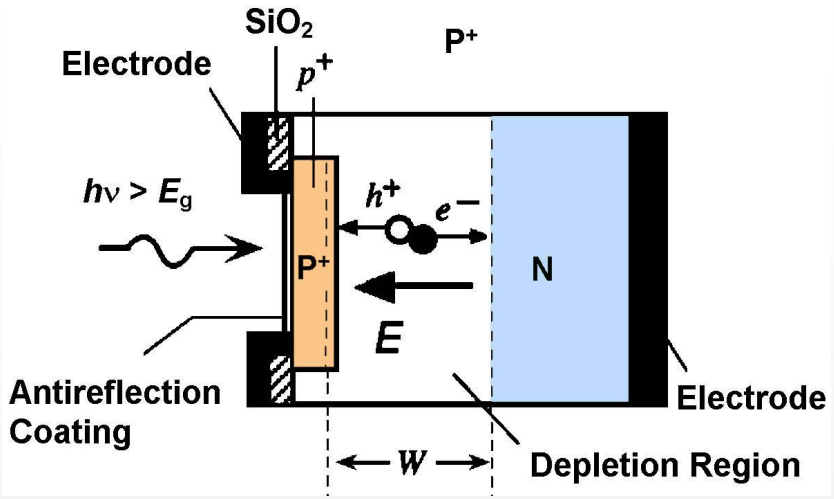


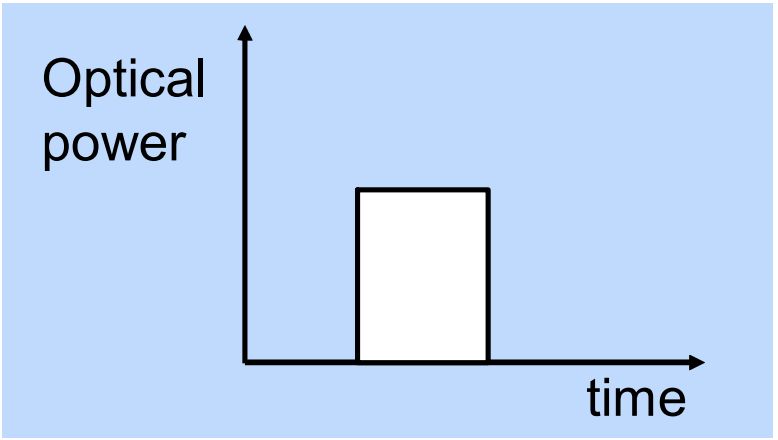

Figure 7-4

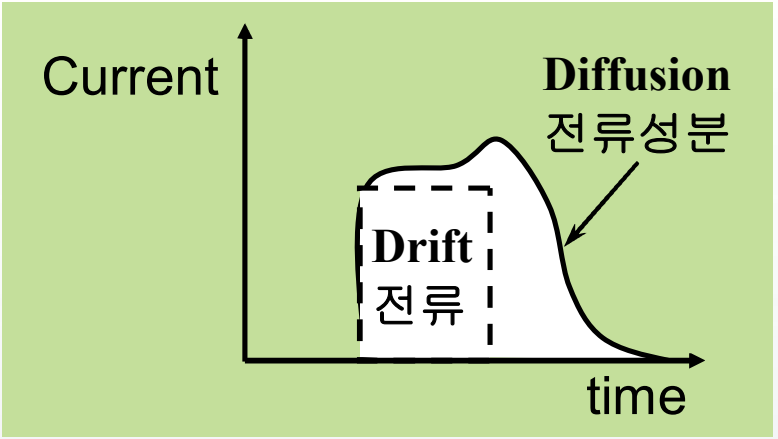
## ■ PN 포토다이오드의 문제점

- 공핍층 밖에서 광 흡수에 의하여 응답도(**Responsivity**) 감소함.

- 확산(**Diffusion**) 전류성분에 의하여 응답속도(**Response Speed**) 감소함.



# 7-4 PIN Photodiode

## ■ 구조

P형과 N형 영역사이에
Intrinsic 영역이 존재함

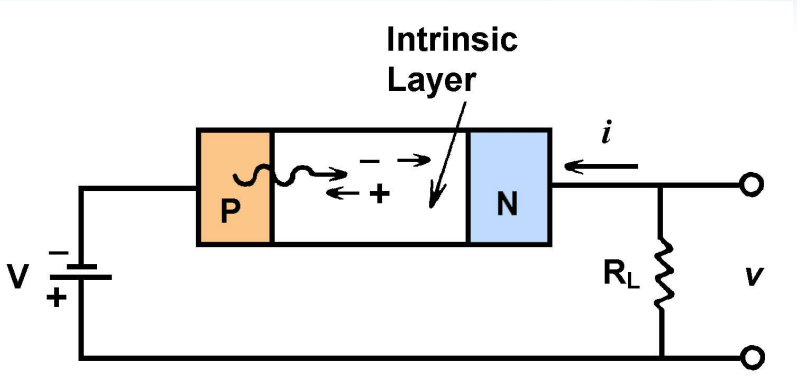
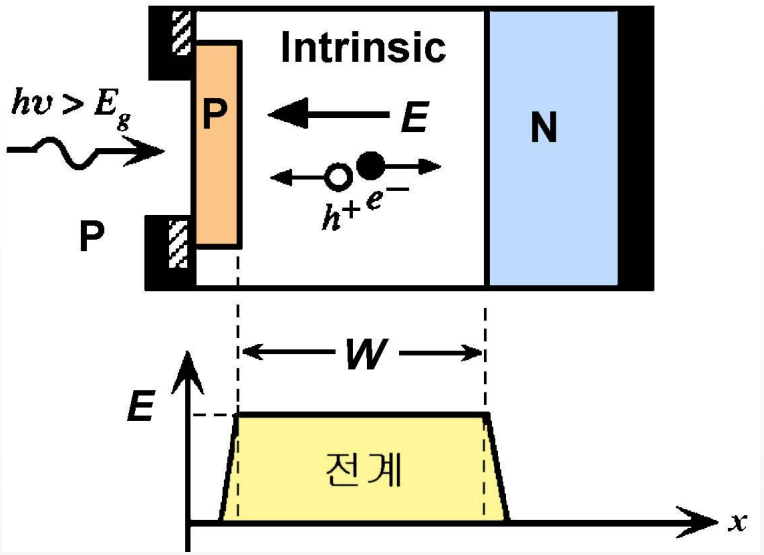



Figure 7-5 PIN Photodiode

## ■ 개선효과

공핍층에서 흡수되는
광량이 증가하여
응답도와 응답속도가
높아진다



## ■ 광검출기의 재료

**Si, Ge, InGaAs**

## ■ 차단파장

$$\lambda_c(\mu m) = \frac{1.24}{W_g(eV)} \qquad (7\text{-}11)$$

(예)

Si : 1.1 ㎛ (1.1 eV)

Ge : 1.8 ㎛ (0.67eV)

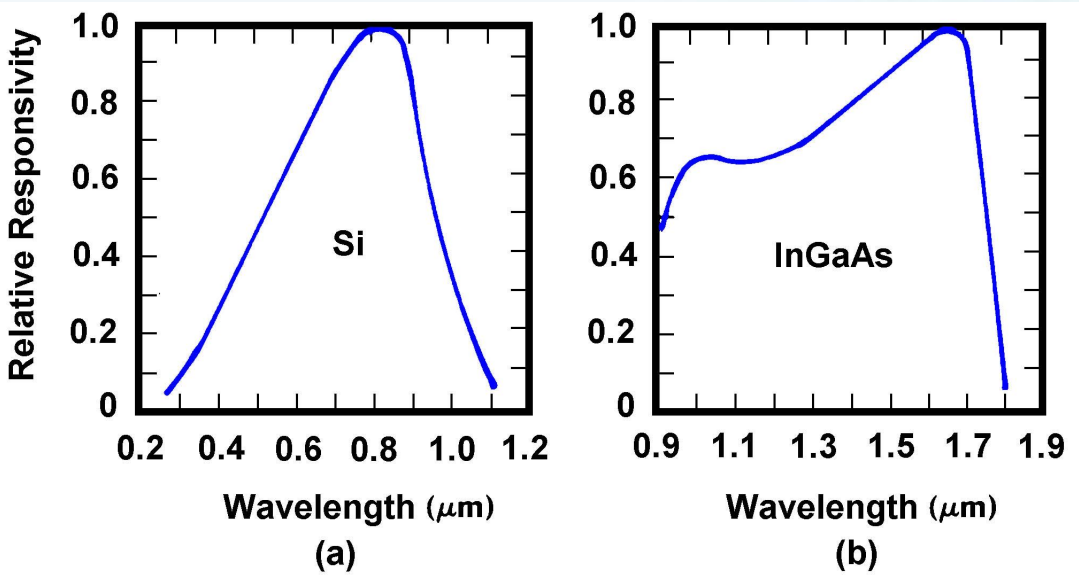
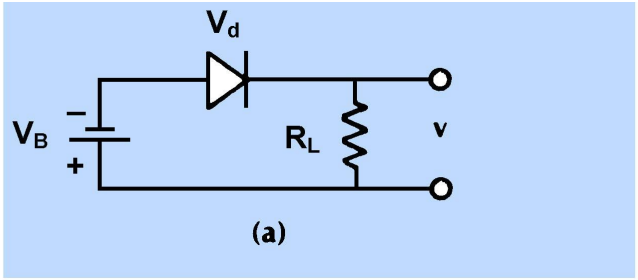



**Figure 7-6 Spectral Response Curves**

**TABLE 7-1. Semiconductor PIN Photodiodes**

| Material | Wavelength Range (μm) | Wavelength of Peak Response (μm) | Peak Responsivity (A/W) |
|---|---|---|---|
| Silicon | 0.3-1.1 | 0.8 | 0.5 |
| Germanium | 0.5-1.8 | 1.55 | 0.7 |
| InGaAs | 1.0-1.7 | 1.7 | 1.1 |

## ■ PIN 수신회로




키르히호프 전압법칙

$$V_B + v_d + i_d R_L = 0$$

Load Line의 기울기

$$-1/R_L$$

입력광 Power 가 매우 크면
선형적 수신영역을 벗어남

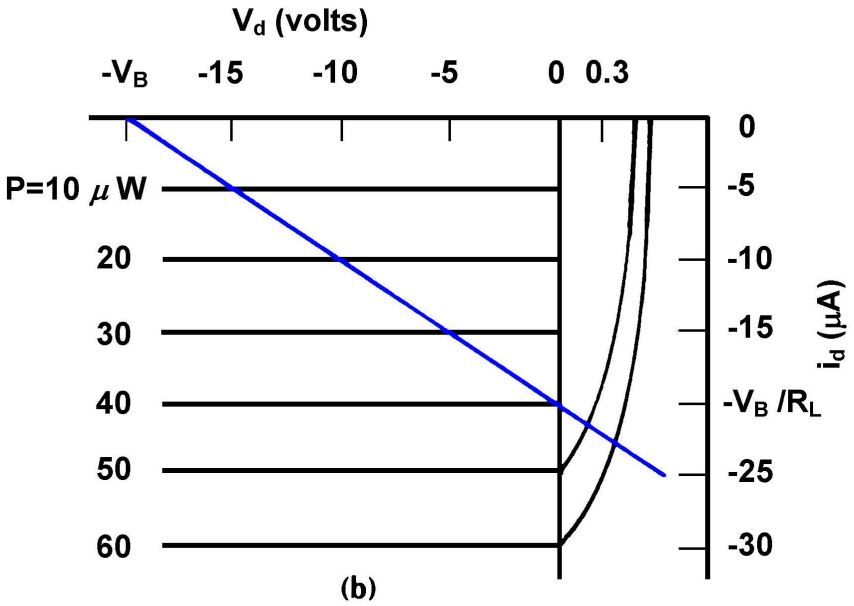
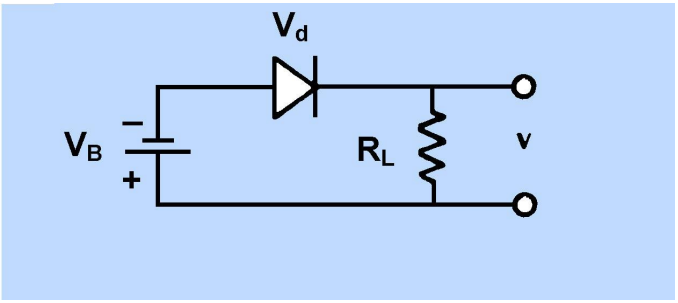



**Figure 7-8** (a) Simple PIN Circuit
(b) Graphical Analysis of the circuit

## ■ Dynamic Range (DR)

$$DR = 10 \times \log(P_{\max} / P_{\min}) \quad [\text{dB}]$$

$R_L$ 을 줄이면 **DR** 이 증가함




### 최대전류

$$i_{\max} = V_B / R_L$$

### 최대 입력광 파워

$$P_{\max} = \frac{i_{\max}}{\rho} = \frac{V_B}{\rho R_L} \qquad (7\text{–}13)$$

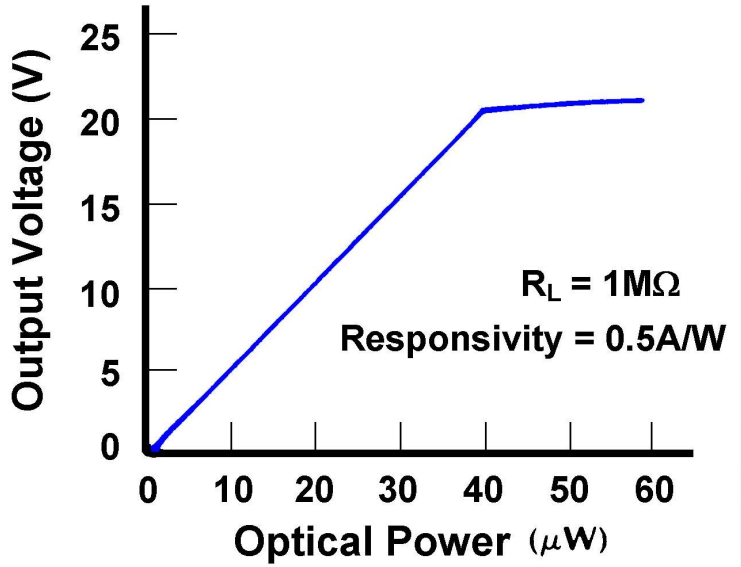
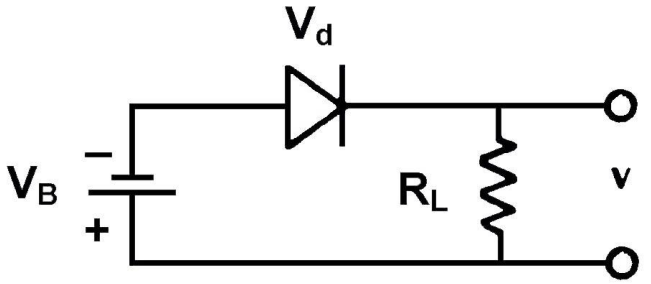



Figure 7-9

## ■ 입력광과 출력전압의 관계

$$v = i \times R_L = (\rho P) \times R_L$$

$$v / P = \rho R_L \qquad (7\text{-}14)$$




## ■ 광검출기의 응답속도

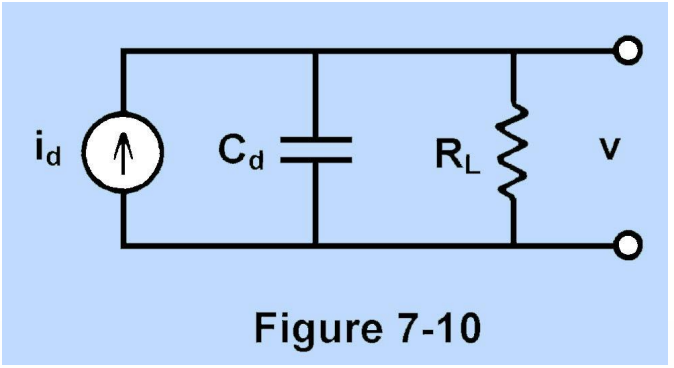



Figure 7-10

**Rise Time**

$$t_r = 2.19\, R_L C_d \qquad (7\text{-}15)$$

**Bandwidth**

$$f_{3dB} = \frac{1}{2\pi R_L C_d} = \frac{0.35}{t_r} \qquad (7\text{-}16)$$

**TABLE 7-3**

| Defining Equation |
|---|
| $v = \rho P R_L$ |
| $P_{max} = V_B/(\rho R_L)$ |
| $f_{3\text{-dB}} = (2\pi R_L C_d)^{-1}$ |
| $i_{NT}^2 = 4kT\Delta f / R_L$ |

## ■ Current-to-Voltage Converter 를 사용한 광검출 구조

OP Amp의 입력 단에서 양단전압, 입력전류 ≅0
(Virtual Ground)

- 포토다이오드 양단전압 : $v_d = -V_B$
- 광검출기의 출력전압 : $v = -R_F\, i_d$

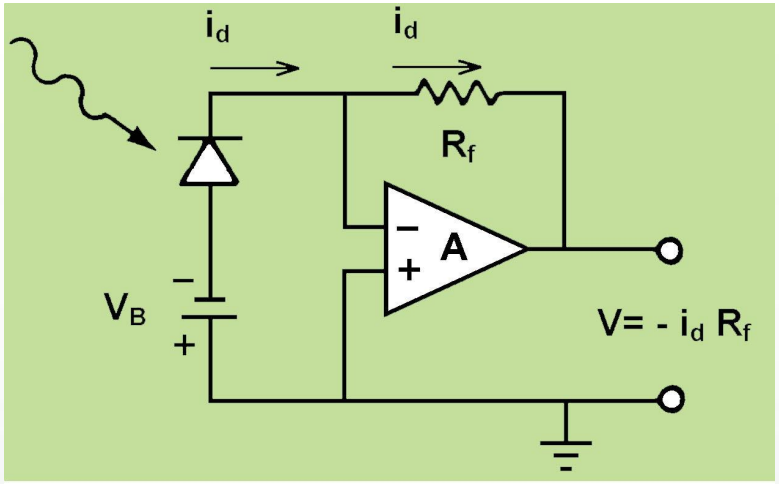



Figure 7-11

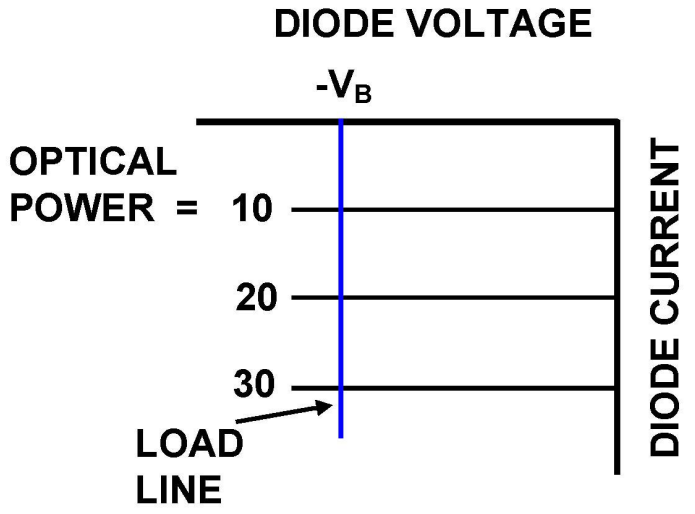



Figure 7-12

# 7-5 Avalanche Photodiode (APD)

## ■ APD의 구조

- 흡수영역(Absorption Region) : 1차 전자-정공 생성
- 이득영역(Multiplication Region) : 전류의 증배 (Avlanche 효과)

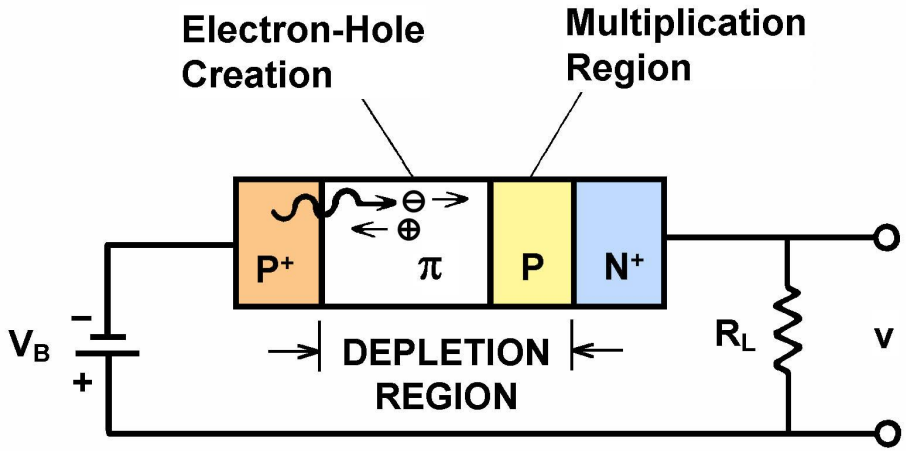
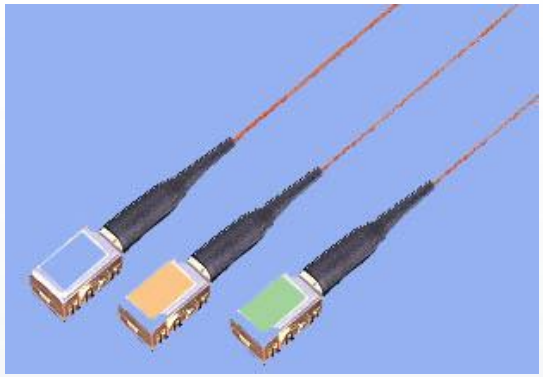
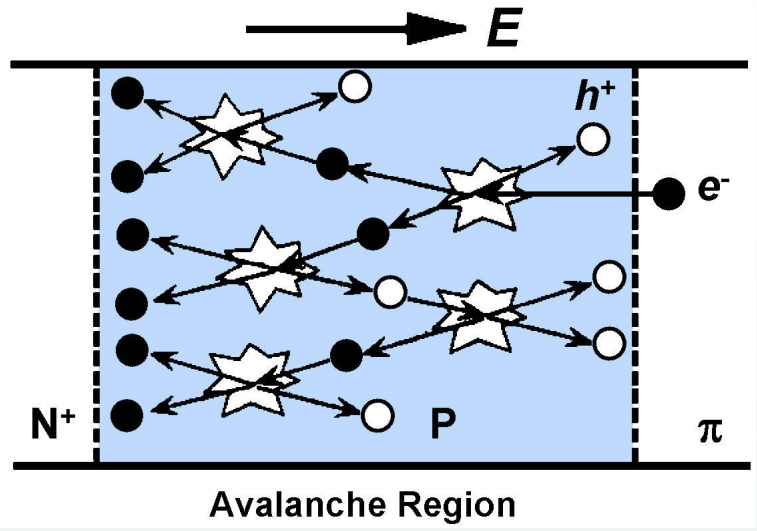


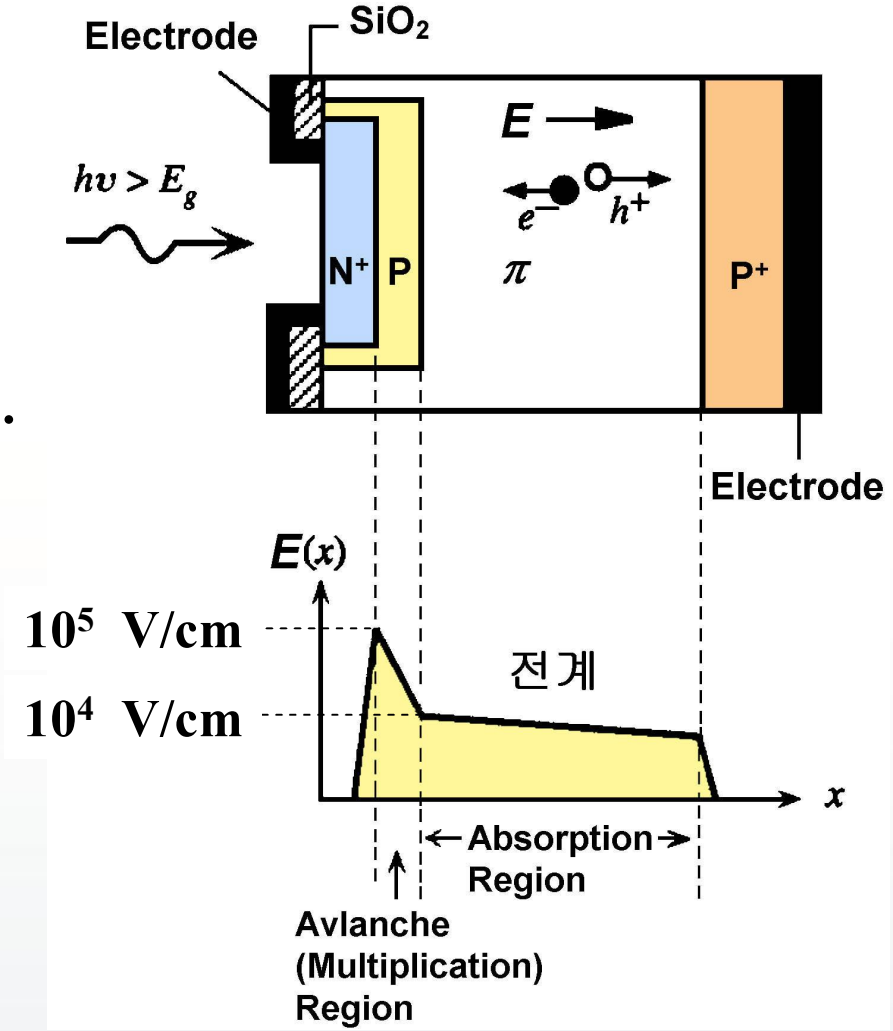

Figure 7-13



## ■ APD 동작원리

- 흡수영역에서 입사광 흡수하여 1차 전자-정공 생성.
- 전자는 PN+ 접합으로 드리프트.
- 이득 영역의 강한 전계에 의하여 충격이온화, 2차 전자-정공 생성.
- 에벌란치 효과에 의하여 전류 급증.



## ■ APD의 전류 증배율

$$M = \frac{I_M}{I_P}$$

## ■ APD의 응답도 (Responsivity )

$$\rho = M \times \left( \frac{\eta e}{hf} \right) = \frac{M \eta e \lambda}{hc} \qquad (7\text{-}19)$$